NANOTECHNOLOGY RESEARCH IN THE US AGRI-FOOD SECTORAL SYSTEM OF INNOVATION: TOWARD SUSTAINABLE DEVELOPMENT

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NANOTECHNOLOGY RESEARCH IN THE US AGRI-FOOD SECTORAL SYSTEM OF INNOVATION: TOWARD SUSTAINABLE DEVELOPMENT

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To my wife Beatriz, Martina and Emiliano

For their infinite patient and love

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SUMMARY

Nanotechnology, the scientific study of manipulating matter on an atomic scale (1 to 100 nanometers) that provides new properties in materials and devices had received considerable research attention and public funding support during the last decade in the US. This emerging technology promises to improve the competitiveness of most of the US industrial sectors. Malerba (2004) an innovation system researcher has developed the theoretical framework "Sectoral System of Innovation (SSI)" to study the process by which new technologies and knowledge are produced and transferred to industrial sectors, where actors interact based on an institutional framework to generate innovation processes.

In this dissertation I studied the agriculture and food processing sector, which is a key sector of the US economy that has provided with enough food for the US population, but in an unsustainable way that has harmed the environment, natural resources and human health. The US agrifood sector is facing new challenges of increasing food demand, which need to be addressed in a more sustainable way that takes consideration on economic, environment, and social aspects. The main questions that this dissertation research focuses on studying how much attention the public nanotechnology agrifood research agenda has paid to sustainability issues during the last decade in the US and what role has played the system's actors in influencing this research agenda. The analysis of the policy process in which system's actors try to influence the research agenda is framed in the Advocacy Coalition Framework (Sabatier 1993) that complemented the Sectoral System of Innovation approach in studying the formation of advocacy groups to achieve their coalition's policy goals.

Three data sources were utilized to achieve my research goals, the CNS-ASU nanotechnology publications dataset 2000-2010(Porter A, Youtie J et al. 2007; De Bellis 2009)which was used to conduct a bibliometric analysis of the agrifood nanotechnology research publications in the US, semi-structured interviews with key actors and their interaction in advocacy coalition groups, and a literature review of several official documents and public hearing with respect to the US nanotechnology system to evaluate the influence of advocacy groups in the policy process. Utilizing Vantage point data mining and Nvivo qualitative analysis software I conducted the data analysis of my research. The results show increasing research attention toward environmental research and food safety issues that can indirectly impact positively on sustainability development, as well as increasing research attention in studying environmental, health and safety issues (EHS) that can reduce potential risks.

The analysis of actors' interaction to influence the policy process, two advocacy coalitions was identified. On one side, a coalition that advocate for more research funding oriented to applied research to achieve the potential that this coalition members believe this technology has to revolutionize the way food is produced giving more competitiveness to the US agrifood sector, this coalition is composed by researchers, federal agency managers and industry representatives. On the other side, a rival coalition that raise concerns respect to potential risks associated to this technology that required to be addressed by the public research agenda. This coalition mainly composed by environmental non-governmental organizations (NGOs) and other social actors claim for a regulatory framework that guarantee a nanotechnology development environmental friendly that benefit the society.

The influence of these two coalitions have succeed in allocating more federal funding resources to research nanotechnology in the agrifood sector, with particular emphasis in EHS research that show the right path to a sustainable development that guarantee enough resources for the future generations.

CHAPTER 1.
INTRODUCTION

Food production has been in the core of the US agricultural policy since the declaration of independence. The first goal of the agriculture sector was to contribute to the economic development of the infant nation, to transform agriculture in one of the most dynamic economic sectors. This vibrant economic growth in the agriculture sector produced a progressive industrialization of traditional farming products into more elaborated food, together with a vertical integration among input suppliers, land owners, farmers, and companies. These actors have joined to shape the US agrifood sector during the last century. New goals have come up since then, they have pushed the federal government to support the agrifood sector with the implementation of a public research agenda.

The new technologies applied to the sector have successfully increased productivity and market competitiveness, but with important detriments on natural resources key for the sector, such as contamination of soil and water streams, lost in biodiversity, among others negative impacts in the environment and human health. Therefore, the challenge that faces the public agrifood research agenda is to consider the consequences that current actions can cause negative effects in the future.

Nanotechnology application in the agrifood sector is an emerging technology promoted by US public research agenda in the last decade, whose supporters believe that it can contribute to increase productivity without harming the sustainability of the sector, meanwhile other system' actors have a different view in respect to this issue. There is very few knowledge about the progress of the agrifood research agenda in regards to this goal. So then, it is relevant to know what type of research orientation has received the agrifood nanotechnology research? And what role has played the actors of the system in relation to influence the policy process by which the nanotechnology has been incorporated into the agrifood sector? My dissertation will address these important questions to contribute to shed light on the link between nanotechnology and sustainability issues. I utilized a mixed method analysis that considered a bibliometric analysis of 10 years period of nanotechnology publications complemented with interviews to key actors of the agrifood sector and literature review of the US nanotechnology development during the last decade.

1.1 Research Background and Motivation

Science has made relevant contributions to the agrifood sector, especially from the middle of the past century up today. The scientific contribution is particularly observed during the last century with the development of high-yield crop varieties in addition to the use of chemicals-based pesticides and fertilizers during the 1960's developed by international agricultural research centers together with national research programs. This technological development is called the "Green Revolution" (Evenson and Gollin 2003). The technological change in the agricultural sector contributed to double the world cereal production in the last forty years (Tilman, Cassman et al. 2002), feeding the world's growing population and reducing hunger and malnutrition problems in most parts of the world. However, despite the successful improvement in farming systems productivity, this development has been done with overexploitation of natural resources, such as soil, water, and biodiversity which has negatively impacted in the environment and society (Tilman, Fargione et al. 2001).

The introduction of agrochemical pest-control inputs also has produced some negative effects in the environment and human health. These negative externalities have been studied in the US by several scholars (Pimentel, Acquay et al. 1992; Pimentel, Harvey et al. 1995; Wilson and Tisdell 2001; Pimentel 2009) who evaluated environmental and economic costs of the use of chemical-based pesticides and fertilizers. Pimentel (2009) calculated as in 10 billion dollar the annual costs in environmental and societal damages produced by the use of pesticides. Among the most relevant unintended negative effects are: public health effects, pesticide residues in food, pesticide resistance in pests, honeybee poisonings, fisher and wild life losses.

The inefficiencies and negative effects caused by the overuse of chemical input in crop fertilization and pest control programs not only have raised negative environmental effects in the agriculture sector, but also in further stages of the food supply chain with an increase in food borne ills affecting human health. Researchers estimate in around20-30% the post-harvest food losses worldwide(FAO 1989; Kader 2004)in both, quality losses (such as loss of caloric and nutritive value, loss of acceptability by consumers, and loss of edibility) and quantitative losses. The post-harvest losses reduce economic benefits of different actors of the food chain from production to consumption.

Modern agriculture and food production system have produced a pressure on agro-ecological and societal systems. However, since 1980’s the concept “sustainability” has received much attention in the scientific community, which refers to a desired goal of development with consideration on three constituent parts; environment, societal, and economic. The concept of sustainable development was defined by the Brundtland Commission of the United Nations(1987) as: “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”This definition has intrinsically worries for the future consequence of the current practices, in which agriculture and food production occupied a central role in food safety not only for the current world population, but also for the future world growing population.

In the following five decades, another period of rapid agricultural expansion is expected, due to the increase in food demand by a wealthier and 50% larger world population, with an expected 9 billion world population in 2050 (Tilman, Fargione et al. 2001; Godfray, Beddington et al. 2010). Under the current agrifood production system, the scenario to increase productivity appears more risky, producing even more pressure over the environment and natural resources. Hence, several experts in the field are calling for a more sustainable way to produce this expansion in order to reduce the damage to the ecosystem and the humanity (Dale 2001; Tilman, Cassman et al. 2002; Millennium Ecosystem Assessment Report 2005; National Research Council 2010). Therefore, the concept of sustainability plays a key role to provide to the traditional agriculture and food production with technologies that can give a response to the goal of increasing production without harming the environment, society, and the economy of the agrifood sector. According to some authors (Tilman, Cassman et al. 2002; Weiss and Lewis 2010) a new emerging field of research coming from nanoscience and nanotechnology might be the solution to shift from traditional agriculture practices toward more sustainable development. Moreover, in the first National Nanotechnology Initiative (NNI) strategy plan was mentioned nanotechnology as a tool to clean pollutant industries and the environment bringing more sustainability to the US industry by reducing energy intensity use, and increase recycling opportunities (Roco, Williams et al. 1999).

1.2 Nanoscience and Nanotechnology

Nanotechnology is the study and manipulation of organisms at nanometric-scale (approximately 1 to 100 nanometer), a research area known as nanotechnology. This technology arises from the interaction of several scientific disciplines, such as physics, chemistry, biology, and engineering. This multidisciplinary study of matter at nano-scale presents unique phenomena and processes. Nanoparticles exhibit new properties that differ from their properties at higher size. Properties such as reactivity, strength, conductivity, and catalyst among others allow the novel applications in several industries.

The unique properties of nanoscale matter have become a source of optimistic expectation to produce a new industrial revolution with the generation of new products and applications worldwide, giving more competitiveness to several national industries. Since then, nanotechnology has been the engine for governments to create national scientific initiative to promote the R&D. In the US, the National Science Foundation (NSF) established the first governmental program dedicated to nanoparticles in 1991, but it was not until year 2000when an interagency national nanotechnology initiative (NNI) was created to join budgetary, managerial efforts, and a unified strategy view to support nanotechnology research as a multidisciplinary field in the US(Roco 2011). Since then, several other countries mimic the initiative to support their own national nanotechnology strategy plan and funding programs.

This scientific development is currently at an early stage, particularly its applications in the agrifood sector, but some sources claim that its applications will create a revolution in the way food is produced (FAO and WHO 2009).

1.3 Nanotechnology in the U.S. Agrifood Sector

The potential application of nanotechnology in the agrifood sector has been reported in areas such as nanocapsules for herbicide delivery, nanosensors for soil quality and food quality, nanoporous zeolites to slow release of pesticides and fertilizers, and packaging for improving the post-harvest life and food quality among others (Scott 2003; Joseph, Morrison et al. 2006; Kuzma, VerHage et al. 2006; Chaudhry, Scotter et al. 2008; FAO and WHO 2009).

The US agrifood sector has been traditionally characterized by government intervention, through price intervention, export subsidies to protect local producers, and a persistent public investment in research (R&D) and development activities to bring competitiveness to the sector (Alston, Andersen et al. 2009). The Department of Agriculture (USDA) has been the main public source of funding for agrifood nanotechnology, that established the first roadmap for nanoscale science and engineering for agriculture and food system in 2002. With the recognition of the relevance of the new research area, the USDA holds a workshop focused on establish a formal research funding program for the nascent agrifood nanotechnology research area. Even though the ambitious first plan that proposed an annual budget of $36.3 million, the budget approved the following year to support nano-biotechnology research in the USDA was less than 10% of the original budget proposed in the roadmap.

The reduction on the federal funding source has also diminished the scope of research orientation in the USDA toward fundamental research in six areas (sensors, identity preservation, smart treatment delivery, smart systems integration, molecular and cellular biology, and materials science), and excluding other such as public outreach and education. The relative low federal funding oriented to agrifood nanotechnology, which is less than 0.5% of the National Nanotechnology Initiative has raised some hypotheses that try to explain the scarce federal resources. One possibility explanation offered by Busch L. (2008)is that the agency has being badly burned by the previous biotechnology research, so then they have decided that nanotechnology could not necessary will pay off. Another possibility is that the nanotechnology R&D in the agrifood sector is led by private sector and they want the public sector far off this potential business opportunity. In spite of the precise reason that explains low public support to agrifood nanotechnology, several authors agree in indicating that the agrifood nanotechnology sector is covered by secrecy and lack of transparency with respect to the research agenda and product development in order to reduce public concern related to potential risk associated to the use of nanotechnology in food(Grobe, Renn et al. 2008; Dudo, Choi et al. 2011; Lyons, Scrinis et al. 2011), as well as a lesson learned by the chemical and seed industry from the controversy that arose in regards to the use of biotechnology applications of genetically modified organism in crops production (David and Thompson 2008).

1.4 Risk Governance in Agrifood Nanotechnology

To avoid preceding mistakes and reduce lack of information of emerging technologies as nanotechnology, several social science researchers have called for the establishment of a new governance regimen of nanotechnology in which the dialogue among actors, such as researchers, policy makers, program managers, industry representatives, public organizations, and civil society address together the research direction and scope to reduce risk and maximize societal benefits(Macnaghten, Kearnes et al. 2005; Rogers-Hayden, Mohr et al. 2007).

Since a decade of public support to nanotechnology research and development in the US, two divergent views with respect to the promises and threats of nanotechnology applications have emerged(Macnaghten, Kearnes et al. 2005). On one side, a group of actors believe in a beneficial view of the application of nanotechnology in this sector, advocating for higher public efforts to invest in R&D nanotechnology agenda for a rapid nanotechnology development of new products and processes bringing higher competitiveness to local industries. On the other side, NGOS and other social actors believe that nanotechnology could increase risks to the environment and the society due to unexpected consequences of the use of engineered nanoparticles (ENPs) such as metallic nanoparticles, quantum dots, carbon nanotubes, in the food processing chain, so then they try to influence the research agenda toward risk analysis research and improve the nanotechnology regulation framework (Miller and Scrinis 2010).

The debate about risks and benefits of nanotechnology research and development in the agrifood sector generate differences in perceptions about the use of this technology among actors that can influence the policy outcome, as well as change in funding and orientations of research agenda. Therefore, it is relevant from the social science perspective inquiry ‘downstream’ of innovation processes and set the research attention into the governance of the new technology, giving the opportunity to all actors of the system express their ideas, expectations, and concerns about nanotechnology from early stages of development. The societal dimension of nanotechnology development was a central aspect of the National Nanotechnology Initiative since its establishment in 2000 in which year they reported an explicit necessity for incorporate to the work of the NNI the research work of social scientists and humanistic scholars, such as philosophers of ethics in the study of social process of setting visions for nanotechnology (Roco and Bainbridge 2001). The incorporating of societal aspect related to nanotechnology in its first national strategy plan in 2000 constitute this emerging technology a particular case to be study, the contribution of the different interest groups to the development of the nanotechnology research agenda in the US. But it is interesting to note that for that first workshop in societal issues none public interest group was invited to express their point of view respect to this emerging technology.

1.5 Theoretical Frameworks

Governance nanotechnology risk and benefits that consider societal implications since early stage of the policy process bring a unique opportunity to study the role that policy actors play in setting the research agenda in a very sensitive sector as the agrifood, it makes the topic of this dissertation one of relevant theoretical interest. I use the intersection of two theoretical frameworks to address the development of the US public nanotechnology research agenda in the agrifood sector and its orientation toward sustainability aspects. The Sectoral System of Innovation approach developed by Franco Malerba (Malerba 2004)from innovation system, and the Advocacy Coalition Framework (ACF) developed by Paul Sabatier and Jenkins-Smith (Sabatier 1993; 2008) from policy process. Both the SSI and ACF are system-based theories that combined well suited the characterization of the US agrifood nanotechnology sector, for instance the SSI allowed me to frame my research analysis in the sector called “agrifood”, which shared a set of activities linked by the food production process where different actors are involved. The study of actors and their relationships inside the system is better achieved by the ACF framework, which identifies the forces that affect the policy process, as well as allowing the study of the role of actors within coalitions and their actions in relation to the nanotechnology policy research agenda and its contribution toward sustainable development.

Sectoral System of Innovation is grounded in the evolutionary theory in which learning and knowledge are key elements of change. The actors involved in the process of change act based on imperfect information, time constrain, and limited by their main’s cognitive boundaries. These characteristics make the learning and decision making process be different, which determine a differential in performance among actors and sectors in a dynamic process of change(Malerba 2005). Malerba define sector as “a set of activities that are unified by some linked product groups for a given or emerging demand and which share some common knowledge” (p. 385). The SSI directs the attention to a holistic study of all components of a specific sector, to this research it is the agriculture and food processing sector that I name as the “agrifood sector”. This theoretical framework focuses on three main dimensions: knowledge and technology, actors and networks, and institutions. I took into account these three dimensions as the units of analysis in the organization of my research, in which the technology is the US public funded nanotechnology research. The actors are researchers, policy makers, and social organizations, such as NGOs and worker unions, who interact in the system to try to influence the nanotechnology research agenda in the US during the last decade. Finally institutions understood as norms, rules, and laws that set the rule of the game by which the actors interact in the system.

Sectoral System of innovation is a very useful framework to achieve my research goals of study the nanotechnology research in the agrifood sector, because it helps me to characterize of the technology in a dynamic manner, setting the technology in the center of the analysis. It also allowed me to identify the actors involved in the system, as well as analyze the institutional framework that governs nanotechnology development in the agrifood sector. Nevertheless, in the network analysis this framework does not fully incorporate the participation of other social actors, such as NGOs, worker unions, and other public organizations that play important role framing the nanotechnology risk-benefit governance.

Therefore, the utilization of Advocacy Coalition Framework to study the interrelation among the system's actors is a contribution to make a most robust framework between innovation theory and policy process to study the intersection between nanotechnology governance and societal issues. The Advocacy Coalition Framework precisely was developed to study the manner different actors who share similar beliefs and views respect to a policy problem work together in order to influence the policy process. ACF introduced by Sabatier and Jenkins (Sabatier 1988; Sabatier and Jenkins-Smith 1993)is one of the most developed frameworks used in public policy to study the policy process. It is composed by actor-based approaches, in which actors from public and private institutions form advocacy coalitions are organized in policy subsystems, which are the most useful unit of analysis for understanding policy change. Each advocacy coalition shows evidence of nontrivial coordination of activities among their actors to influence and manipulate the rules and personnel of government institutions to achieve their goals over time. Advocacy coalition's actors come from a variety of positions, such as politicians, interest groups, bureaucrats, applied researchers, journalists, and leaders (Mintrom and Vergari 1996). They have in common a set of policy beliefs based on their hierarchically ordered beliefs. On the top of this hierarchy there are deep core beliefs and policy core beliefs, both being more normative and resistant to modification in response of new information, this set of beliefs are considered by Sabatier and Jenkins as the stickiest glue that binds coalitions together. On the bottom of this hierarchy are secondary beliefs more susceptible to be modified with respect to external source of information.

The study of nanotechnology development, the actors involved in the system, their interactions in advocacy groups, and the role of institutions that shapes the rules of the game by which nanotechnology has been developed in the last decade in the US are key factors in understanding the research agenda setting and the potential effects of nanotechnology in the agrifood sector related to sustainable development.

1.6 Research Question and Methodology

The role that the different actors of the public nanotechnology research agenda plays in the agrifood sector is a key factor to understand how the research agenda had evolved in the last decade in the US. This sector is of special research interest due to the conflict poses by using an emerging technology with not conclusive safety studies. Provide with enough food to the growing population is just one dimension of the traditional food production dilemma. Alternatives to this system has been developed, such as the organic food production system, which seek to avoid the use of chemical-base input in the crop production or any other artificial modification in to the food they consume. This alternative production system that makes emphasis in the sustainability of the food system to produce healthy and natural food have a critical perspective respect to the use of technology in the food, in particular they have opposed to the use of biotechnology, in particular in relation to the use of genetically modified organism (GMOs). Recently a similar negative perception regarding the use of nanotechnology in the food is arising among the organic food organizations. This negative perception respect to potential increase of risk when nanotechnology is applied in food can make them an antagonist groups that could influence the nanotechnology research agenda in the agrifood sector.

The considerations of arguments and influences from other groups as the organic ones are usually given apart from the nanotechnology governance. The consideration of the different actors that directly or indirectly can be affected by the nanotechnology development need to be considered in early stages when the public research funds are first set up. This type of governance of emerging technologies could warranty more transparency of the system and higher technological adoption by users and consumers.

My dissertation studies three relevant aspects of the agrifood nanotechnology research agenda: the study of the nanotechnology development and how the knowledge and technology development is changing with respect to the US agrifood nanotechnology research agenda in the last ten years, the actors and their interactions to influence in the research agenda, and the role that actors from coalitions influence institutions in the agrifood nanotechnology research agenda setting in the US.

The requirements of increasing food supply in the near future could produce an even more negative pressure over the US agro-ecological systems, the environment, and people. This threatening scenario requires taking a close attention on the contribution that nanotechnology can make in the agrifood sector to continue increasing food productivity but in a more sustainable approach. Therefore, the goal in this dissertation is to provide me with the knowledge to understand and provide answers to my main research question: Did the formation of advocacy coalitions affect the attention paid to sustainability issues in the agrifood research agenda?

This is a crucial question to understand from early stages what role plays the composition of the US agrifood system in the nanotechnology R&D agenda setting.

To address the main research question, I considered the following three sub questions:

i. How much attention does sustainability receive in research on nanotechnology applications in the US agrifood sector and how has it changed over time?

ii. What actors are involved in the US agrifood nanotechnology research agenda and do they form advocacy coalitions?

iii. What role do the advocacy coalitions play in the shaping of the agrifood nanotechnology research agenda in the US agrifood sector?

In order to provide a response to my research questions I conducted a case study research of the US agrifood nanotechnology system. Utilizing the Sectoral System of Innovation approach I characterized the US system, and the Advocacy Coalition Framework allowed me to study the policy process by which actors of the system interact to form advocacy groups to influence the US nanotechnology research agenda. I conducted a mixed method study, with a bibliometric analysis that help me to characterize the agrifood nanotechnology in the US with the use of the CNS-ASU nanotechnology bibliometric data set 2000-20010 developed by researchers at Georgia Tech (Porter A, Youtie J et al. 2007; De Bellis 2009). I complemented my research inquiry with a qualitative analysis to study the presence of advocacy groups, their members, actions and beliefs respect to nanotechnology in agrifood. I made 24 interviews with relevant actors, such as researchers, policy makers, agency managers, NGOs, and worker organizations. Finally, I utilized the Nvivo 9.2 Software for complement my qualitative analysis with the analysis of several official documentation, reports, and media coverage of the agrifood nanotechnology sector in the US. This software allowed me to organize the documentation in nodes with respect to the opinion expressed by the participants referred to the agrifood nanotechnology linked to sustainable issues, the entities (actors), attributes (beliefs, arguments, and resources), their relationships (coalitions) and their connection to the agrifood nanotechnology research agenda setting and regulations in the US and its contribution toward a more sustainable development. More details about the research method of my dissertation are described in Chapter 3.

1.7Significance and Contribution

This research looks into the development of a cutting edge nanotechnology in the agrifood sector and study the interaction of the actors involved in the US innovation system. The US agrifood sector is a good case of study due to its components such as, land, producers, food process companies, research organizations, and institutions remain relatively stable over time, for example the US Department of Agriculture, the main federal agency oriented to support scientific research in the agrifood sector was created more than 150 years ago. Nowadays, USDA is leading the public nanotechnology research agenda in the US. This sector has historically used technologies as agronomic management, irrigation systems, seed hybridization, pest control management, and recently biotechnology developed of genetically modify organism (GMOs) with funding coming from the government, who has been the main promoter of a successful model to produce and transfer knowledge into innovations.

This research seeks to study with particular attention the relevance of participatory approach in the public research agenda setting from a sectoral innovation systems approach, and help to the understanding of the role of governance to increase sustainable development with new technological applications such as nanotechnology.

This research attempts to fill the knowledge gap of the US nanotechnology agrifood sector by utilizing the strength of the innovation system theoretical approach and the advocacy coalition framework from policy process. The agrifood nanotechnology has received less attention with respect to uses and potential consequence than other sectors such as the electronic, chemical and pharmaceutical industries (House of Lords 2010). Also, the development of nanotechnology research in the agrifood sector has received sparse attention among social science researchers. This lack of information has been reported by researchers as Kuzma & VerHage (2006) quoted “Although nanotechnology is broadly receiving attention in public and academic circles, oversight issues associated with applications for agricultural and food production remain largely unexplored. Agrifood nanotechnology is at a critical stage in which informed analysis can help to shape oversight activities and decisions” (p.1)

Therefore, the importance of this research is to fill the knowledge gap in regards to nanotechnology applications in the agrifood sector, and also study how the institutions and actors of the system influence the research agenda. This dissertation research seeks to analyze the evolution of the research in agrifood nanotechnology, study the actors of the system, their interaction in advocacy groups, their resources, arguments and beliefs with respect to how the value conflict between them can influence the US nanotechnology research agenda related to sustainability issues.

This research contributed to support policy makers to generate a better understanding of the interactions within the US agrifood innovation system and the role that different actors play in the public research setting. In addition this study can be useful for those scholars interested in studying innovation systems and dynamics of emerging technologies. Malerba pointed out in a recent publication about sectoral systems that the relevance of the agrifood sector in the innovation system has been explained by its “massive ‘carrier’ in the application of new technologies and harnesses the benefits of technological progress.” (Malerba and Nelson 2012) (p. 197)

1.8Structure of the Dissertation

This dissertation is compound by 7 chapters. In Chapter 2 I conducted a literature review that support the theoretical framework used in my research, together with a revision of the main concepts and the research questions of my dissertation. In chapter 3 I described the US agrifood sector and the entities that are involved in the research agenda setting and concluded with a description of the data and methodology utilized in this dissertation to give response to my research questions, at the end of this chapter I present the advantage and limitations presented in the data and methodology of this research. In Chapter 4it is presented the results of the bibliometric analysis of the research publications in nanotechnology during the period 2000-2010 with emphasis in the US case, which is the research focus of this dissertation. In this quantitative analysis I utilized a searching and clarification strategy to find the trend in publications of the US agrifood nanotechnology research. Following with Chapter 5 where it is presented the qualitative analysis of semi-structured interviews and revision of official documentation complemented with media information of the different actors involved in the nanotechnology agrifood sector. This analysis allowed me to find the presence of advocacy coalitions groups, their beliefs, arguments, organizations, and interaction to try to influence the public nanotechnology research agenda. Chapter 6 analyzes the actions taken by each coalition in influencing the institutional framework of nanotechnology. Finally in chapter 7 I wrote the conclusions and I present the main findings, the limitations of this research and also some policy implications from my research.

CHAPTER 2.

LITERATURE REVIEW

2.1 Introduction

This chapter analyzes the theoretical background utilized in the study of the agrifood nanotechnology public research agenda conducted during the last decade in the US. Particularly the literature review of the Innovation System and Advocacy and the Coalition Framework are considered, the two main theoretical frameworks taken into account in this dissertation. The innovation system approach from evolutionary theory developed by researchers interested in study technological change and the process through which determined countries and sectors learn and accumulate knowledge, and the ACF approach from policy process which study the actor's interaction who join in coalitions to influence policy making process. Both theories help me to reduce the knowledge gap respect to the research strategies and orientations of the US agrifood nanotechnology public research agenda in relation to sustainability issues.

This chapter also describes the current state of the art of the nanotechnology research and it relationship with the US agrifood sector. The evolution of the institutional framework that sets the rules by which this technology has been developed in the last ten years, as well as the concept of governance to articulate the public interest that some social science researchers have incorporated to the discussion of the policy process by which nanotechnology has emerged.

The last part of this chapter is focused on further specifying the research questions that drive this dissertation.

2.2 Sectoral System of Innovation

The innovation system approach represents a useful theoretical framework to study the public nanotechnology research agenda in the US agrifood sector. The innovation system has emerged as a relevant framework to study the innovation processes that occur in a delimitated boundary, which according to Carlsson (2002) system is defined as "a set of interrelated components working towards a common objectives" (p. 234)The system is made up of the interdependence of three dimensions: components, relationships, and attributes, in which change in one dimension can also influence upon other one. The components of the system can be actors or entities involved in the generation and transfer of knowledge, and institutions that frame the rules by which the system works. The relationships are based on the interaction among the different actors and institutions of the system. With higher level of interaction among the components make a more dynamic system, in which change in one component can modify characteristics and performance of another one. The third dimension of the system is the attributes represented by properties of each component of the system that frame their interrelationships, such as robustness, flexibility, openness, response to change, which are among the most important ones(Carlsson, Jacobsson et al. 2002).

The study of innovation process has received high attention in different level, national system that studies the innovation process within a geographic delimitation at national level (Lundvall 1992), regional, and sectors. The selection on level of analysis is given by boundaries in terms of geographic, time, and knowledge base dimension.

The Sectoral System of Innovation is a theoretical framework developed from the systems of innovations approach, in which the innovation and production take place in a specific sector. The system is framed by a knowledge base, firms and other relevant actors, networks, and institutions that interact amongst each other to shape the innovation and production dynamic, that occurs in specific economic sectors. Malerba defined sector as a set of activities that are unified by some related product groups for a given or emerging demand and that share some basic knowledge(Malerba 2004). The dynamic is particularly different for each system, and it can vary with respect to their characteristics, such as the number of actors involved, their composition, competences, expectation, beliefs and goals. This characteristic can affect the learning process that takes place inside the system, and the type of technologies and the knowledge base utilized in their innovation processes.

SSI focuses on change and transformation, with a dynamic view of innovation, considering aspects from the evolutionary theory of authors such as Nelson, Dosi, and Metcalfe (Dosi and Nelson 1994; Metcalfe 1994), as foundational bases, who consider the actors beliefs, objectives, and expectations as key factors to understand the learning process and actors' decision making process. The sector represents a set of activities linked by product groups and actors involved in the production process, such as firms, scientists, consumers, research organizations, financial institutions, industrial organizations, among the most relevant actors of the system. The sectoral system of innovation arises from the concept that each industrial sector has their own particularities in regards to the knowledge learning process and the transfer of them.

The use of SSI gives a better delimitation of boundaries and structures in three main units: actors, institutions, and networks in a sector in particular. The sector analysis identifies and characterizes the actors and their interaction, it permits the understanding of the learning process as well as under what conditions innovation happen, the types of sectoral transformations, and the factors that determine the country performances (Malerba 2004). The advantage of using SSI in my research is related to facilitating the analysis of a particular production sector, such as the US agrifood, and the transformation of this sector due to the use of a particular technology as the nanotechnology research in the last decade. The lack of related agrifood studies that utilize the SSI framework make this work relevant to contribute to the enhancement of this framework, because agrifood is a relevant sector related to employment and economic development for many countries.

SSI mainly focuses in firms' innovation activities, and most of its applications that have been used to characterize the manufacturing industry. This centralization on firm behavior of SSI has been criticized (Geels 2004) by ignoring the interaction of other actors in the system, such as users, as well as a reduced attention given to the role of institutions, taking into consideration the centralized study focus on actors such as firms. Moreover, the development of nanotechnology in the agrifood sector has been occurring under a climate of limited information, due to potential public concerns about the risk brings about by this technology in human health, environment and safety issues(Busch 2008). This silent environment reduces the chance of obtaining empirical data to conduct an analysis of the US agrifood research agenda, as well as can reduce the learning process due to the lower level of interaction among the system actors. This also reduces the transfer of knowledge and could affect the decision making process due to imperfect information.

Even though the innovation system give a useful theoretical framework to study the dynamics by which the knowledge obtained from nanotechnology can be characterized based on the components, relationships, and attributes of the agrifood system, giving a clear delimitation of the system and components, the analysis that make by the interrelationships of the actors is weak respected to incorporating other relevant social actors into the policy process and analyze how these actors advocate to influence the policy process. From the public policy perspective these social actors can also play a relevant role in the agenda setting, a topic of importance to this dissertation with respect to study what role these actors play in the system to influence the public research directions, thanks to the incorporation of their opinion and arguments into the policy discussion. Therefore, I complemented the use of SSI with the Advocacy Coalition Framework (ACF), which is a theoretical framework that helps to study the policy process by which different actors are involved in a particular policy problem, and under what conditions they join in coalition based on two parameters, a common set of beliefs and evidence of nontrivial coordination activities among their members to influence policy designs and processes.

Since previous technology development as the biotechnology in the agrifood sector, scholars have shown that social actors play a preponderant role in the shaping of the research agenda, and their set of belief can determine a very active participation in the policy discussion respect to the use and adoption of a new technology, with particular attention in the agrifood sector, that not only concern to policy makers and firms that the SSI is focused, but also the interaction of other actors such as, social scientists, NGOs, and public organizations that advocate for more transparency and control respect to the use of the new technology. Because a limited orientation toward emphasizing the benefit obtained from nanotechnology research and development from an optimistic view of economic benefits to the market, but reducing resources to study the potential unintended negative consequences, which can jeopardize the technology adoption by the population(Miller and Scrinis 2010). Moreover, some researchers argue that the role of social science research has been oriented to increase the public acceptance of nanotechnology in order to avoid previous experiences of public resistance in relation to genetically modified organism from biotechnology(Sandler and Kay 2006).

Hence, the intersection of sectoral system of innovation with the advocacy coalition framework allowed me to address the dynamic by which the nanotechnology system has been developed in the US agrifood sector during the last ten years. Likewise, type of forces, if I found discovered in my research, have contributed to shifting the research agenda toward more sustainable issues. With a nanotechnology research agenda that consider not only goals in increasing productivity and economic development, but also take into account other dimensions of sustainability development as the care for the environment and the protection of the human health. The ACF gives more robustness to my research inquiry with respect to the interaction among actors that form coalitions to deal with the nanotechnology policy discussion.

2.3 Advocacy Coalition Framework (ACF)

Since 2000, the formation of the National Nanotechnology Initiative (NNI) has established the national roadmap for the nanoscale science and engineering research and development in the US. The main goal of this initiative has been to increase the understanding and control of matter of nanoscience and nanotechnology applications to produce a technological revolution in the US industry to gain competitiveness and improve benefit to the society (The White House 2000).

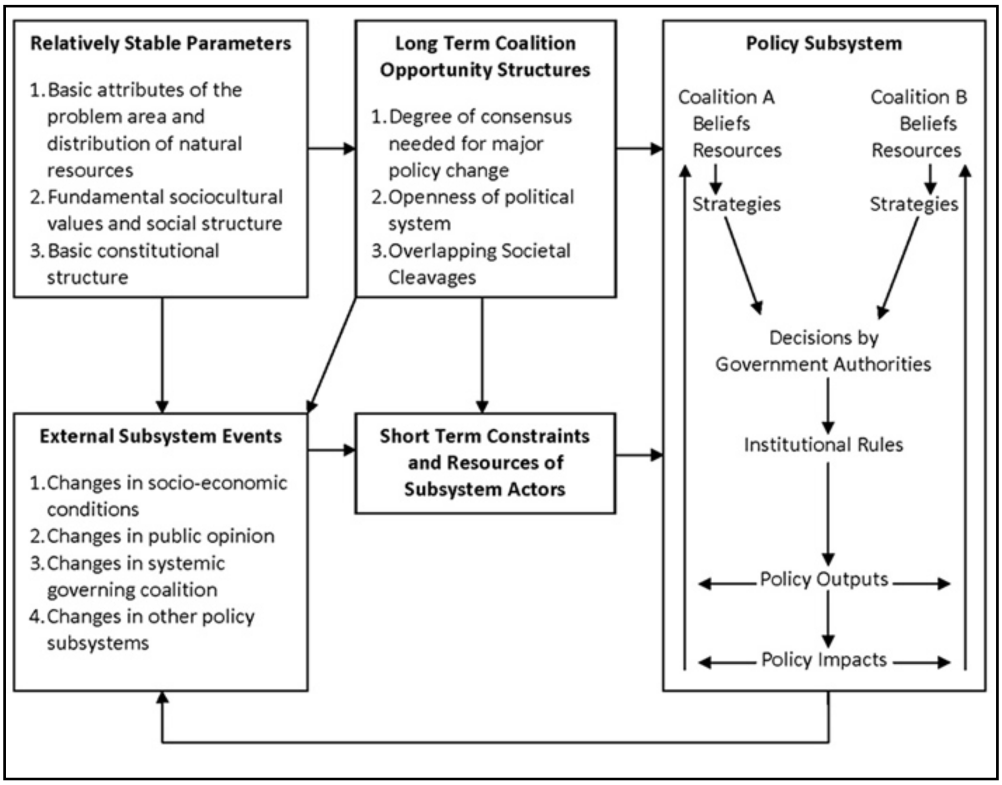
A decade later, concerns related to safety and potentially negative effects of the use of ENPs in human health and the environment have occupied an important place in the research agenda. These two-opposite views with respect to benefits and risks associated with the nanotechnology research agenda in a particularly sensitive agrifood sector have transformed the issue in a policy debate. In this debate, not only policy makers and researchers are involved, but also societal actors and NGOs who demand more participation in the policy process, arguing for more regulation to reduce additional risks and trying to influence the research agenda toward more social and environmental friendly practices(Maynard 2010).   This problem is one that has a difficult solution due to goal conflicts, disputes among different and multiple actors, and difficulties to recognize the real benefits and costs because of incomplete information.

ACF is one of the most developed frameworks used in public policy to study three aspects of the policy process, understanding coalitions, learning, and policy change(Sabatier and Weible 2008). It is composed of actor-based approaches, in which actors from public and private institutions that form advocacy coalitions are organized in policy subsystems, with determine the boundaries of the policy debate in which the interaction among coalitions is produced. Subsystems are the most useful unit of analysis for understanding policy change. Each advocacy coalition shows evidence of nontrivial coordination of activities among their actors to influence and manipulate the rules and personnel of government institutions to achieve their goals over time. Advocacy coalition's actors come from a variety of positions, such as politicians, interest groups, bureaucrats, applied researchers, journalists, and leaders (Mintrom and Vergari 1996). They have in common a set of policy beliefs based on their hierarchically ordered beliefs. On the top of this hierarchy are deep core beliefs and policy core beliefs, both being more normative and resistant to modification in response to new information, this set of beliefs are considered by Sabatier and Jenkins as the stickiest glue that binds coalitions together. On the bottom of this hierarchy are secondary beliefs more susceptible to be modified in regards to external sources of information.

The ACF identified three forces affecting policy. The first is the policy-oriented learning, which mainly refers to "substantive learning that deals with the severity of the policy problem, its causes, the probable impacts of alternative solutions, etc" (Sabatier and Jenkins-Smith, 1999, p. 155). The second driver involves changes in the real world, particularly the shock of external events, which consider changes in public opinion, changes in governing coalitions, and outputs from other subsystems that are out of the control of subsystem actors. The third is related to turnover in personnel which constitutes another non-cognitive source of change(Sabatier 1999). According to the authors, policy change, normally occurring over a period of a decade or more, is a function of both competition within the subsystem and events outside the subsystem. Policy subsystems are broad in scope, and at any given time they may contain a number of advocacy coalitions with one dominant coalition, and just few other subordinate ones (Sabatier and Jenkins-Smith 1999). Changes of actors' beliefs can contribute to understanding the development of the policy outcome.

The basic elements and variables of the ACF are presented on Figure 1. This diagram has been revised and improved since its first version of 1998. The main change observed in this last version is about the internal subsystem shocks and negotiated agreements between coalitions are as much as relevant as external shocks with respect to change in the policy process.

Internal shock promoted by coalition's participants that share core set of beliefs which are homogeneous and stable overtime. Weible, Sabatier, and Mc Queen (2009)made a comparative study that analyzed about 80 research's that utilized the framework in their respective research. They found the stability overtime of coalitions, but at the same time they disagree with respect to homogeneity aspects of the framework in relation to sharing the same core beliefs among members. The differences in homogeneity among members of a same coalition are explained in part by Weible and Sabatier(2005) who find the existence of sub coalitions, they describe these sub-coalitions as coalitions in which some members remain together because they share similar set of policy core beliefs against a common opponent, but they also can be internally divided in regards to differences related to some policy core or secondary beliefs, that make them to organize these sub-coalitions.



Source: University of Colorado Denver (2011) based in 2005 ACF diagram.

Figure 1: Diagram of the Advocacy Coalition Framework

The Advocacy Coalition Framework has been utilized in several case studies of different policy areas, such as energy, environmental, genetic engineering, and forestry certification, just to name some. Weible made a complete compilation of studies that used ACF (Weible 2009). For instance, a previous study about the change in the genetic engineering German policy system conducted by Nils Bandelow (2006), which utilized ACF as the theoretical framework to understand the coalition structure, found the development over time of two advocacy coalitions by performing cluster analysis on the basis of expressed policy positions. One coalition was integrated by actors that generally supported the use of genetically modified organisms (GMOs), and another coalition was comprised of opponents to the use of GMOs. Contrary to the central assumption of the ACF with respect to the core beliefs determined the formation of coalitions, this study revealed that the sharing of general attitudes was the link among actors involved in a coalition.

The focus of the ACF is on policy learning and policy change within a policy subsystem. Policy change was initially thought to occur as a result of policy learning or external shocks. External shocks include public opinion, changes in governing coalitions, and outputs from other subsystems (Sabatier & Jenkins-Smith, 1999). More recent iterations of the ACF have added internal (subsystem) shocks, and negotiated agreements between coalitions as factors influencing policy change (Sabatier & Weible, 2007).The use of scientific and technical information is a key aspect of the ACF to study the policy process, several studies have focused in studying the role played by scientists as coalition members(Litfin 2000; Weible 2007; Weible 2008). This framework is useful to study political systems with relative high openness as the US federalism system, in which the policy process is characterized by decentralization and diversity in policy actors' participation.

The application of the ACF to over hundred studies globally in diverse policy areas has shown it to be a useful theoretical framework to study the policy process in regards to controversial issues as important as my research topic related to nanotechnology development in the agrifood sector.

ACF presents some similar approach to study policy change with respect to other two theoretical frameworks, multiple-streams and punctuated-equilibrium. They all point to similar type of events and factors that determine a policy change, such as salient events, crises, change in governing coalitions, and focus in administrative and legislative events. But what make ACF to have a special advantage over the other two theoretical frameworks is that ACF pays close attention to events that occur inside a policy subsystem, which is the source of a policy change (Schlager 1999).

In my research advocacy coalition theory offers the framework to study the collaboration between actors that engage in advocacy groups to influence policy process with respect to the US public research agenda in agrifood nanotechnology, this framework offer two criteria to identify coalitions. First, people from a variety of positions who share a particular belief system with similar values that make them to perceive a particular policy problem from similar angles. Second, advocacy groups shows evidence of nontrivial coordination of activities among their actors to influence and manipulate the rules and personnel of government institutions to achieve their policy goals over time(Sabatier 1993).This framework has been applied to several policy subsystem in the US, in which context seems to work well, because the US political system is characterized for being pluralist, in which system different actors can engage in the policy debate.

However, the advocacy is a policy framework that is still under constant revision by scholars, see for example the last revision conducted by the main promoter of the framework (Weible, Sabatier et al. 2011). There are some particular issues of the nanotechnology policy debate that could be not addressed by ACF, for instance the role that play those actors that can influence the policy process, but who are not part of any coalition, such as the public in general. Another issue that ACF give only a partial response is when analyzes a policy subsystem in which some members are also relevant actors of another policy subsystem. What we can learn from the analysis of previous cases? For example, the study of GMOs debate and the role those environmental NGOs have played in this policy subsystem, could potentially be applied in a different policy subsystem such as the agrifood nanotechnology ones.

So far, over the more than 80 studies that considered ACF as its theoretical framework agreed in two findings. First, the coalition members remain relative the same over time, and in second term the policy core beliefs of members function as the glue of the coalition by which members remain over time working together. Weible et al (2009) argue that new emerging areas of research have started to receive some theoretical and empirical attention such as to learn more about the type of coordination within and between coalitions.

2.4 The US agrifood System and its Institutional Framework

The world agricultural development has been characterized by a pivotal government support to R&D and extension. The US Agrifood sector has been traditionally characterized by government intervention with respect to subsidies to protect local producers, price policy for agricultural products, and a persistent public investment in research and development(R&D)activities to bring competitiveness to the sector (Alston, Andersen et al. 2009). For instance, the role of government in the seed and plant program for improvement and adaptation to local conditions was successfully conducted by public funding programs. In 1862 was created the Department of Agriculture (USDA)the main public organization oriented to promote the research and development in the US agriculture sector , and 25 years later the Morrill Act allowed the creation of land-grant universities (Kloppenburg 2004). The early institutionalization of the agriculture R&D capacity in the US established a systematic scientific framework to study the main problems in the agriculture sector.

However the foundation of the agricultural research public institution in the middle of the 19th century, the technological change in the US agrifood sector was only generated after the Second World War with the so called Green Revolution. Although the important advancement of agriculture research previous the II World War US, farmers did not have enough economic incentives to adopt these technologies (Cochrane 1993).

The scientific contribution to agriculture sector was massive introduced since the 1960's in major cereals production such as, rice, wheat, and maize. This technological advancement produced particularly by public research organizations was called "The Green Revolution" which considered the utilization of chemical-based pesticides and fertilizers together with the improvement of the genetic resource of crop's seeds which increased crops yields. The increase in productivity thank to this technological revolution took away fears of a global shortage of food needed to feed the growing world population, increasing standards of life of millions of people taking them out of poverty, but it was insufficient to solve the problems of poverty and hunger in many small farmers of rural areas (Evenson and Gollin 2003).

After the implementation of the Green Revolution, the agriculture system changed to a more industrialized sector. The technological change suffered in the agrifood sector after the green revolution affected in special the US small size farms. The modification of the farming business received the so called "technological treadmill effect", in which only early adopters obtain the economic benefits from innovations, usually large farmers with higher capital resources and knowledge than the small ones (Cochrane 1993). The new technology adoption leads to over-production and product prices fall. So then, technology adoption becomes a necessary condition to remain in business, but for later adopters is no longer profitable invest in the new technology because at that late phase of the innovation process, the potential benefit got with greater productivity is overridden by the lower prices obtained. This effect has produced concentration of farming activities at large scale. However, the negative effect of technology change in part of the rural population of later technology adopters, the reduction in prices of agri-food products benefit urban populations, because they could obtain better quality and cheap food, improving their nutrition, health and life expectancy. This phenomenon was evidenced in the agriculture sector of the US North Central region (the US Corn Belt), where between 1935 and 1960 the number of farms dropped by 35%(Kloppenburg 2004).

The technological treadmill effect has contributed to the transformation of the composition of the rural population in the US. In 1900 29.2 million of Americans were living in rural areas, which represented 39% of the total US population. Today the rural population in the US is only about 2.9 million or 1.1% of the total population (Alston, Andersen et al. 2009). Small farms (defined as those with gross cash farm income less than $250,000 yearly) represent 91% of all farms and 23% of the total US agriculture production. Among small farmers, more than 60% have incomes lower than $10,000. This group located at the lower end of small farmers is classified as noncommercial farms (R. A. Hoppe 2010). Small farmers are more vulnerable to the effects of technology adoption in the agrifood sector, especially with respect to the treadmill effects, and so they are a group that requires particular attention when scholars study sustainable development.

The increase in crop yield has been the main goal in public agricultural research agenda, carried on principally by university researchers. Nevertheless, during the last decades the U.S. public agricultural R&D spending has grown at decreasing rates, for instance, during 1950-1970 the annual percentage of growth was around 4%, this has declined to less than one percent in the period 1990-2007. this reduction in the growth rate of public investment also has diminished the productivity rates, and the funding research orientation have shifted from crop productivity toward other concerns, such as environmental effects of agriculture, food safety, food quality, and energy (Alston, Beddow et al. 2009). In the US in 2000, the public R&D expenditure was $3.8 billion meanwhile the private sector invested $4.6 billion, showing and increase up to 55% of the total share in participation of the private sector in relation to year 1981 with only 44% (James, Pardey et al. 2008). Hence, an increased portion of the US agricultural R&D is performed typically by suppliers of agricultural inputs, instead of the historically high contribution of public sponsored research organizations (Moschini and Lapan 1997).

Studies conducted by economists have shown positive impact of the public investment in agriculture R&D and extension services, in special respect to gain in productivity. For instance, in the US a research conducted by (Alston, Andersen et al. 2009) showed a net benefit of $18 per dollar of additional federal research, and a net benefit of $32 per dollar invested by State Agricultural Experiment Stations in the period 1949-2002. The author’s benefit/cost analysis of the US public agriculture R&D considered the productivity growth as the main benefit source and the public R&D

investment as the main source of costs. In spite of the impressive contribution of public agriculture R&D in the US in the last half century, this kind of economic analysis of benefit/cost misled other biases in estimated payoff, such as negative externalities produced by this sector (Norton 2005).

Public research organizations played a key role to produce scientific knowledge to the benefit of the all society. In 1980 with the dictation of the Bayh-Dole Act, this intellectual property regimen promoted innovations transfer from government-funded research results to private sector increasing the participation of agrifood companies in R&D activities. Intellectual Property regime allowed exclusive right of using new products and process to the patent's owners, unless the owner decides to share the use of a technology with others by a royalty fee payment. This new scenario increased the R&D investment and produces a faster technological development in the agrifood sector.

Bayh-Dole not only transformed the high-tech industry, but also low-tech as the agrifood sector. The concentration of new agrifood products and services in few individuals generated a privatization of a public good. For instance, most of the R&D conducted in public research organization and government-funded finished soon or late in private hands. Agrifood companies interested in these technologies bought these patents to have the exclusive use of these technologies and so obtain a competitive advantage respect to their competitors. Companies' owners of these patents become powerful, growing fast and getting the higher market share, first in local market and late internationally. The seed industry is a good example of the industrialization process of this sector, a highly fragmented industry become dominated by only few transnational corporation.

The US Intellectual property rights regime has become to be an important institutional framework of R&D activities in the agrifood sector. Patents, copyrights, trademarks, and trade secrets are all sources of property right protection, among which patents are the most powerful tools of protecting intellectual property rights. In 1994 in the Uruguay round of GATT was established the Trade-Related Aspects of Intellectual Property Rights Agreements (TRIPS), which enhanced the intellectual property regime among the country members of the World Trade organization (WTO). TRIPS contained a set of rules in relation to the intellectual property by the enforcement of mandatory adjudication, with a dispute settlement system that guaranteed the protection of new inventions among the WTO states members (Helfer 2004). Plant protection as a special regime called the World Intellectual Property Organization (UPOV) convention, which was adopted in 1961 by three European countries, the Netherlands, UK, and West Germany. Later, other new members joined to UPOV and it has been revised several times since 1961. Under this new IP regime, plant varieties need to fulfill three requirements to be protected under UPOV convention, must be new, distinct, and uniform (Dutfield 2008).

Since the establishment of the UPOV convention, the agrifood R&D has been transformed, with high participation of private agrifood companies that focus their efforts on conducting the agrifood research agenda toward chemical and food-processing, as well as crop and animal technologies more oriented to improving productivity in capital-intensive commercial agriculture, and paying less attention to other factors , such as environmental and socioeconomic considerations (Pardey and Beintema 2001).

This intellectual property regimen which has promoted a market concentration in few transnational corporations has been one of the main critics received from civil society organizations that claim an asymmetric in distributions of the benefits from new technologies as the GMOs that have been captured by monopolistic powers, increasing the technology dependency of farmers by transnational corporation.

The agriculture development strategy conducted in the last century has reduced the threat of food scarcity, but at the same time, it has increased the overexploitation of natural resources, generating more pressure on agro-ecological systems that will require doubling the food supply by 2050 (Tilman, Cassman et al. 2002; Godfray, Beddington et al. 2010). This threatening scenario requires a more active role of public agricultural R&D organizations in setting research toward a more sustainable development.

After a decade of research and development of the nanotechnology in the US, the system still has not adequate legal tools to implement a complete regulatory framework to control the nanotechnology development. The U.S. Environmental Protection Agency (EPA)main mission is the protection of human health and the environment. EPA recently recognized its lack of both, reliable information or processes to effectively manage the human health and environmental risks of ENPs, and its lack of administrative ability to deal with the challenge offered by nanotechnology in the US regulatory framework (EPA 2011).

This weakness in the institutional framework has followed a similar path as the biotechnology. The lack of labeling of GMOs in the US by regulatory agencies is just one example of a pattern that nanotechnology products have followed, the US Food and Drug Administration (FDA) have neglected to implement a labeling policy for agrifood nanotechnology products, facing the tradeoffs between economic-cost and ethical aspects of consumers right to know and choose what they consume (Kuzma, Romanchek et al. 2008; Kuzma and Priest 2010) .

The two more significant technological changes in agriculture were the “Green Revolution” in the 1960’s and later the biotechnology in the 1990’s they have contributed to productivity enhancement, with different level of success, but at the same time with increasing environment and social costs, such as the soil erosion, water contamination, air pollution, and increase in diseases related to the use of agrochemicals. During the last decade the nanotechnology development in this sector has become to be a wicked problem, which is represented by Sabatier as those problems of difficult solutions because on one hand, it could have the potential to reduce current environmental problems caused by farming activities, but on the another hand, it can increase uncertainty and risks in regards to potential negative effects in the environment and human health with the use of nanoparticles in food production.

2.5 Sustainable Development

The concept of sustainable development in this research is an attempt to integrate the economic development with environment and social considerations that can contribute to increase productivity without diminishing the natural resources utilized in the process, and reducing negative effects that have characterized the US agrifood production sector. The incapacity of the agrifood system of assess the technological impact of emerging technologies such as biotechnology and nanotechnology have risen the critics from social scientists and social organizations respect to the real benefits that those technologies have been a positive contribution to the system, with a constant absence of capacity to estimate and reduce the risks associated to the utilization of new technologies. For instance, the development of pesticides to control plant pests and diseases in the so called green revolution, has allowed the improvement of crops productivity increasing the benefits to farmers and consumers with more food available at lower prices, but at the same time it has also increase the health and environmental risks of the global population. Only in the US more than 300,000 cases of human pesticide poisonings occurring annually, causing a serious health problem particularly among rural population who are in constant exposition to chemical based pesticides, as well as increasing the pollution of soils and water streams causing damages to the natural life and the environment (Pimentel, Harvey et al. 1995).

The projected increase in the world's population by 2050 that will raise the food demand will require that new technologies in the agrifood sector will take into consideration not only improvement of productivity, but also the reduction of side effects produced to the environment and humankind. (Tilman, Cassman et al. 2002) defined sustainable agriculture as "practices that meet current and future societal needs for food and fiber, for ecosystem services, and for healthy lives, and that do so by maximizing the net benefit to society when all costs and benefits of the practices are considered" (pg. 671). The concept of ecosystem services is important for understanding the system in which agriculture works, furthermore which factors are under risk of an overexploitation of this system. This concept was first developed by scholars such as George Perkins (1864) and Aldo Leopold (1949) who wrote about the importance of natural resources and the use and abuse of them. Gretchen C. Daily (1997) defined ecosystem services as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life." (pg. 3) Among the services that deliver the ecosystem are: Pest control, insect pollination, fisheries, climate regulation, soil retention, food control, soil formation, cycling of matter, composition of the atmosphere, maintenance of soil fertility, and maintenance of a genetic library.

Sustainable development is required to be taken into account when research agendas are implemented radical innovation such as the nanotechnology. Sustainable development that includes three domains, the economic, the environment, and the social, at the same level of relevance share the principles of the World health Organization "Millennium Ecosystem report" (2005) that encourages policy makers to integrate principles of sustainable development into country policies to preserve and restore environmental resources to reduce poverty, and to increase human wellbeing and development.

The concept of sustainable development was defined by the Brundtland Commission of the United Nations (1987) as: "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainability entails considerations of people, the environment and the economy (see Figure 2). This definition has intrinsically worries for the future consequence of the current practices, in which agriculture and food production occupied a central role in food safety not only for the current world population, but also for the future world growing population.

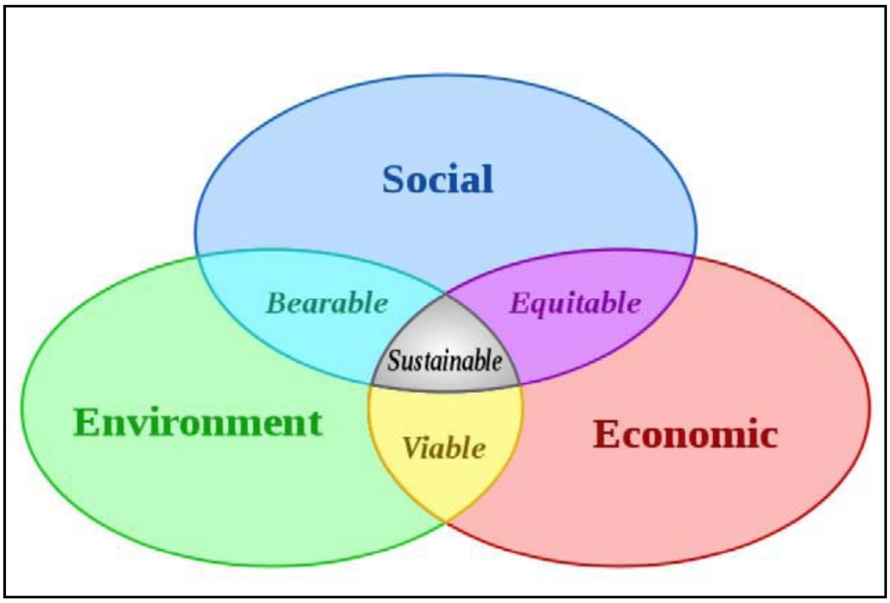


Figure 2: The three Pillars of Sustainability (Brundtland 1987)

Sustainability concept in the agriculture sector was legally addressed by the US Congress in the 1990 "Farm Bill" (Food, Agriculture, Conservation, and Trade Act of 1990 :FACTA[2] revised in 2007), which defined sustainable agriculture as an "integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource base upon which the agricultural economy depends;

[2][*Subchapter I: Findings, Purposes, and Definitions*, U.S. Code, Title 7, Chapter 64-Agricultural Research, Extension and Teaching, Available at GPO Access: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=browse_usc&docid=Cite:+7USC3103(12/05/11)]

- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations; and
- enhance the quality of life for farmers and society as a whole."

Sustainability development in the agrifood sector is defined by FACTA and complemented with the UN Commission on Sustainable Development, and the sustainable goals articulated by the National Research Council Committee on twenty-first agriculture system, establishing a four dimensional goals of sustainability in the agrifood sector. I used this definition of sustainability goals to study the orientation of the US agrifood nanotechnology research toward sustainable development (see Table 1).

Table 1: Four Dimension Sustainability Goals

1. Satisfy human food, feed, and fiber needs, and contribute to biofuel needs: i. Increase productivity of farming practice/food processing ii. Improve quality and safety of food output iii. Affordability of farm output iv. Availability of farm output v. Food security/ nutrition security	**2. Enhance environmental quality and the resource base:** i. Improve agricultural water productivity/wastewater management ii. Sustainable agriculture/reduction in agrochemical use iii. Maintain soil quality and health iv. Biodiversity v. Mitigation practices of Greenhouse gas/air pollution/Ozone depletion vi. Adaptation to global climate change vii. Land use change/land degradation/erosion/desertification viii. Waste management ix. Animal health and welfare
3. Sustain the economic viability of agriculture and food production: i. Ensure farm business profitability and viability ii. Farm/food production labor economic security iii. Community economic security iv. Access farmers to financial support v. Access farmers to new technologies vi. Access farmer to markets	**4. Enhance the quality of life for farmers, farm and food industry workers, and society as a whole:** i. Ensure farmers and their households acceptable quality of life ii. Access to health services and retirement benefits iii. Protect the health and welfare of farmers, farm/food processing workers, and society iv. Enhance community or social well-being from surrounding agriculture, access to local food, sustain provision of ecological services, and maintenance of attractive landscapes v. Public awareness, participation, and information vi. Governance/role of civic society

Source: by the author based on the UN Commission on Sustainable Development Indicators of Sustainable Development and the National Research Council, Committee in the Twenty-First Century Systems Agriculture (2010)

The authors Hopwood and Mellor (2005) attempted to make a classification of the different meaning of the concept "sustainable development", which varying with respect to the proponent, from neoliberal economics that pay no attention to environment and equity issues, to eco-fascist that provide extreme importance to the environment concept or socialist that focus their attention to equality issues. In the words of the author, the concept has evolved from "the growing awareness of the global links between mounting environmental problems, socio-economic issues to do with poverty and inequality and concerns about a healthy future for humanity" (2005, p.39). In my research I utilized the concept of sustainable development in a manner to enhance the focus of analysis from a biased orientation to economic development toward a more wide scope that considers human development as well as environmental effects.

Sustainability concept in nanotechnology research in the agrifood sector is articulated in two opposite means. On the one side, nanotechnology research promises to contribute to the mitigation of the negative environmental and human health effects, for example, reducing the use of agrochemicals. But on the other side, nanotechnology faces a potential increase in environmental and health risks due to the use of nanoparticles.

Among the nanotechnology applications several researchers have identified techniques that potentially can contribute to reduce the current negative socio-economic and environment impact produced by the agrifood sector. Meanwhile, others authors have noticed about potential risks to the environment and society associated with the application of nanotechnology applications in the agrifood sector.

In the US, since the establishment of the first National Nanotechnology Initiative strategy plan in 2000, the concept of sustainability in the agrifood sector occupied an outstanding role. This plan considered that nanotechnology can improve agricultural yields for an increased population, with contributions in two main areas, such as water filtration and desalination, and providing with enable renewal energy sources. This report projected saves in world energy consumption by 10% and reductions in more than 200 million tons of carbon emissions (Roco 2001).The last NNI strategic plan in 2010 report "Nanotechnology Research Directions for Societal Needs in 2020" (Roco, Mirkin et al. 2011)by first time recognized sustainability as an issue of relevance to be consider in the establishment of the research agenda. Moreover two chapters of this report were dedicated to this issue. For instance, Chapter 4 "Nanotechnology Environmental, Health, and Safety Issues" describe the challenge that this new technology have to face to achieve a safe and sustainable development, which includes environmental, health, and safety (EHS) aspects and of ethical, legal, and social implications (ELSI) issues, supporting research in areas such as energy, water, food, raw materials, and climate. This research focus can contribute to increase productivity, more sustainable development, and the creation of new jobs. In the same report in Chapter 5"Nanotechnology for Sustainability: Environment, Water, Food, and Climate" the authors recognized the key role that play nanotechnology for providing renewal energy, clean water, and improve food supply.

Mihail Roco the Senior Advisor for Nanotechnology in the National Science Foundation and main NNI promoter, in a revision of goals and achievements of the nanotechnology initiative in the US during the last ten years refers to sustainable development as one of the goals that have been not realized yet because of a lack of enough funding research. Projects such as nanotechnology for energy solutions, water filtration and desalination, and climate research, in which he postulate among one of the ´potential reasons of the unfunded program in sustainable development as a lack in pull and collaborations of stakeholders that are less organized than in other sectors (Roco 2011).

Similar approach to present nanotechnology as the technology capable of making a big contribution toward sustainable development has been offered by Barbara Karn (2005),a former manager in the National Center for Environmental Research at the U.S. Environmental Protection Agency (EPA), who noticed that nanotechnology can offer response to five categories of sustainability:

1) Global climate change,
2) Depletion of natural resources, including water, forest products, minerals, and fossil fuels,
3) Population problems, including infectious disease,
4) Urbanization and social disintegration, income gaps, and
5) Environmental degradation, which consider pollution problems, threatened habitats, and loss of biodiversity.

In her view, nanotechnology offers useful tools to generate a research in environmental applications, she proposed that regulatory agencies as EPA make the environmental nanotechnology research with informed awareness about potential negative consequences and focusing on making sustainable choices to reduce risks.

To better assess benefits and risk from nanotechnology applications, several social scientist and social actors have called for the implementation of a risk governance of nanotechnology since early time in the establishment of the nanotechnology public funding research (ETC Group 2003; Roco and Bainbridge 2005; Renn and Roco 2006; Karinen and Guston 2010), which required to consider the point of view from different stakeholders involved in the system, not only researchers but also civil society organizations as well.

2.6 Nanotechnology Governance

The term governance is used to describe a transformation in the manner government used to regulate technologies, using methods to reduce regulatory gaps, improve coordination among different federal agencies that promote the nanotechnology initiative to enhance the research and development, and promote industry and stakeholder participation to establish an environment of transparency in the system. nanotechnology governance must try to move from a top-down approach to a bottom-up legislative approach which attempts to regulate this emerging technology with the participation of all stakeholders involved in the system, with a more equal political power distribution among the different actors. The nanotechnology governance allowed the consideration not only of optimistic point of view respect to the contribution of this emerging technology, but also the consideration of the concerns that may arise from social actors that claim for more participation in the regulation process of nanotechnology, generating a system in which the opinion of users, consumers and workers need also being taking into consideration when new technologies are developed in stages previous to the technology is transferred to the market.

Since an early stage before the NNI was established in the US, the study of societal aspects of nanotechnology was considered as a relevant factor of the responsible innovation. The National Science and Technology Council (NSTC) Subcommittee on Nanoscale Science, Engineering, and Technology (NSET) and the National Science Foundation organized a workshop in 2000 in which the importance to have the participation of social scientists studying the nanoscience processes and the nanotechnology development since early stages was emphasized(Roco MC 2001). In this aspect, the studies in social, economic, ethical, and legal dimensions of the nanotechnology development can contribute to the creation of a broad capacity for "anticipatory governance" to enhance awareness and anticipate potential unintended effects of the new technology. Michael Roco(2003)quoted with respect to the anticipatory governance as "an appeal is made to researchers and funding organizations worldwide to take timely and responsible advantage of the new technology for economic and sustainable development, to initiate societal implications studies from the beginning of the nanotechnology programs, and to communicate effectively the goals and potential risks with research users and the public." (p. 181)

Guston and Sarewitz were one of the social scientist scholars that make the link between social science studies and nanotechnology. They proposed the term "real-time technology assessment (RTA)" to frame the mechanism by which the social science and policy research can be integrated with innovation process of emerging technologies as the nanotechnology, and suggested the use of RTA as component of “anticipatory governance” to deal with controversies generated from innovations, such as the nuclear power, GMOs, and the more recently development of nanotechnology and its benefit-risk distribution to opportunely communicate and make early warning to public to be prepared to the application and acceptance of the technology before its reach the market (Guston 2002).The concept of anticipatory governance has been constructed based on a variety of lay and individuals and collective group of stakeholders, who shape the issues of the emerging technologies before these evolve, such as the issue of benefit-risk of nanotechnology development. (Barben, Fisher et al. 2007).

2.7 Nanotechnology and Risk

The main driver of the NNI program to support nanotechnology research in the US has been oriented to scientific research that rapidly can be transferred to innovative technology to increase the competitiveness of the national industry sectors and place the US industry as the world leadership in nanotechnology research and development. The promise of an economic development thanks to the public investment in nanotechnology research has been among the strong arguments to call for a federal initiative that implement the research agenda in the US. The vision expressed by the stakeholders related to nanotechnology of pushing for the generation of a national strategy to develop nanotechnology was observed since the first workshop organized by the Interagency Working Group on Nanoscience, Engineering and Technology (IWGN) in 1999, in that occasion the IWGN met with stakeholder groups from Federal agencies, industries, universities, and professional societies to evaluate the research directions that nanotechnology should follow in the US to coordinate efforts to develop a wide range of revolutionary commercial applications (Roco, Williams et al. 1999). This workshop revealed only potential beneficial impacts from nanotechnology, but it ignored the necessity to invest public funding to study societal implications from the nanotechnology research, in particular those ones oriented to study potential negative implications, such as the study of potential risks. Similar approach was observed in the first NSF workshop in “Societal Implications of Nanoscience and Nanotechnology” (Roco and Bainbridge 2001), in which Thomas Kalil the Deputy Director for Policy for the White House Office of Science and Technology Policy quoted “I think that we need to start thinking of the potential risks and downsides… I think there a couple of directions that we can move down that may be fruitful — one is to identify particular applications of nanotechnology that are going to be broader societal objectives in areas like environment and health..” (pg. 22)

In 2003, Roco (2003) recognized the importance of studying societal implications of nanotechnology research, as he wrote “Government investments in nanotechnology have jump-started the development of the field, and government activities should equally prepare the societies for the future implications..” (p. 184). Since then, societal aspect of nanotechnology were included in the federal funding program, but restricted to social, ethical, legal, economic and workforce implications, with almost none emphasis on risk.

The research in environmental, health, and safety issues of nanotechnology (EHS) become an important components of societal implications of nanotechnology research, in 2003 the Nanotechnology Environmental and Health Implications (NEHI) working group was created with the objective to organize and prioritize the EHS research under the NNI frame to conduct well-informed risk assessments of nanomaterials. Risk assessment has been defined as the process that use factual base information to analyze and determine the likelihood of harm caused by the exposure of individuals or population to hazardous substances (Council 1983).

Since 2003 the NNI intergovernmental agency research funding for EHS has been around 5% of the total annual budget oriented to nanotechnology research, which represented $38 million in 2006 (National Nanotechnology Initiative 2006).

The US federal funded EHS research has been severely criticized by social organizations that consider that an important aspect of the nanotechnology and its impact in the ecosystem and society is underfunded and incomplete. Scott Frickel called this condition of insufficient public support to conduct relevant research areas as nanotechnology the “undone science” (Frickel, Gibbon et al. 2010).

2.8 Agrifood Nanotechnology

The US National Nanotechnology Initiative defines nanotechnology (NNI) as “the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.” (NNI 2011) At this scale, the properties of materials differ with respect to their physical, chemical, and biological properties. These new characteristics open the development of new materials with novel properties. Nanotechnology is in an early stage of development, which promises to improve current agriculture practices through the enhancement of management and conservation of inputs in crops and animal production (IFPRI 2011). Even though potential benefits from nanotechnology in agrifood sector, public concerns have risen about the lack of knowledge in relation to potential negative effects on human health and the environment (ETC Group 2004; Chaudhry, Scotter et al. 2008).

The potential increase in risk has opened the public debate of the real contributions that nanotechnology can do for the sector in particular and the society in general. This discussion has been characterized by divergent point of view with respect to the promises and threats (Macnaghten, Kearnes et al. 2005). Agrifood nanotechnology opens even more suspicions about the role of this technology in the sectoral development and its contribution to the society in general. Moreover, The agrifood nanotechnology has received less attention related to uses and potential consequence than other sectors such as the electronic, chemical and pharmaceutical industries (House of Lords 2010). This reduced information respect to the nanotechnology research and development has increased the criticisms from social actors as NGOs that claim for more transparency (ETC Group 2010).

Nanotechnology development in agrifood sector will occur under a much higher food demand than the last century due to the expected world population growth of up to 9 billion in 2050. Nevertheless, improvement in productivity should not be the only goal as it has been traditionally, as currently the world faces threats, such as global climate change, environmental pollution, water scarcity, soil erosion, and lost in biodiversity (Godfray, Beddington et al. 2010). Sustainable development approach that considers economic, environmental and social aspect are required to be considered in the establishment of the agrifood nanotechnology research agenda, in order to reduce the negative effects of food production. In a study conducted in the field of biotechnology applications in food production, Einsiedel and Goldenberg (2004) compared lessons obtained from biotechnology that nanotechnology can learn from, they concluded with the necessity to develop social tools for nanotechnology innovation and governance in early stages, in order to embed the R&D in nanotechnology with societal needs and to ensure a long-term sustainability. Therefore, the importance of this research to filling the knowledge gap with respect to nanotechnology applications in the agrifood sector, studying the characteristics of the system that can determine a research agenda that considers sustainability development issues.

Nowadays, the agrifood sector is facing a new technological change led by the scientific research development in nanoscience and nanotechnology. The United States is one of the world leaders in agrifood nanotechnology development, governmental institutions such as the National Science Foundation (NSF), the Department of Agriculture (USDA), and the US Environmental Protection Agency (EPA) are main actors of the agrifood nanotechnology research agenda and also principal sources of public funding for nanotechnology research, which is conducted in several public and private research organizations across the US. (Kuzma 2005).

Since the first public initiatives that supported nanotechnology research in the US agrifood sector a decade ago, the nanotechnology application in the agrifood sector is a controversial topic among different policy actors who differ in the benefits that this technology can bring to the sector. This difference in views produces the formation of two rival coalitions. On one side, a group of actors formed mainly of researchers that advocate for a strong public promotion of research and development in nanotechnology to transform completely the production, distribution, commercialization, and consumption of food. Utilizing "bottom-up" manufacturing technology which consists of the development of building blocks at atomic level, they claim the possibility to produce new engineered nanomaterials with new properties than the current agrifood inputs and provide more competitiveness to the US agrifood sector. For instance, proponents of research in the field of nano-fertilizer and nano-pesticides mention the possibility to reduce the current high amounts of application of those inputs, reducing negative environmental effects and producing higher effects in crop production. With nano-encapsulation techniques it is possible to step down the chemical release under controlled situations, reducing the current application dosage and improving efficiency (Sastry, Rao et al. 2007). Applications in food packaging are another potentially sector that will receive the benefits from this technology. With the use of nanocomposites with new thermal and gas barrier properties, they can prolong the post-harvest life of food, and this application could facilitate the transportation and storage of food (Sozer and Kokini 2009). These examples of potential contributions of the nanotechnology are used by proponents to advocate for a more strong public support into nanotechnology research.

On the other side, an opposite vision has been presented by a group of political and social actors. They claim that nanotechnology applications in agrifood pose higher threats on environment and human health, which could increase environment and social hazard due to unknown potential negative effects of ENPs, such as metallic nanoparticles, quantum dots, carbon nanotubes in the ecosystem. Potential risks embedded in nanotechnology research can generate public resistance and reduce the information level with respect to the research agenda, particularly research conducted by the private sector. Several scholars support the argument that agrifood companies, such as chemical and food processing ones that could be working in nanotechnology research and development are trying to avoid mentioning it to reduce potential public concerns about nano-applications in food (David and Thompson 2008; Hepburn, Holder et al. 2008). This environment of secrecy around nanotechnology in agrifood sector increases the difficulties in accessing data and information about the actors involved in research activities, their interactions, and the areas of research developed (Kuzma, VerHage et al. 2006; Busch 2008; Kuzma, Romanchek et al. 2008). The Helmut Kaiser Consultancy(2004)estimated in more than 600 agrifood companies working in nanotechnology research worldwide are involved in this area, with the US as the world leader followed by China and Japan. This report projected a market size of nanoproducts of around US$20.4 billion in 2015.

Hence, three relevant aspects of the agrifood nanotechnology research agenda in the US require a deep study of the US agrifood public nanotechnology research, in order to analyze if this emerging technology is promoting the public research agenda toward more sustainable practices. First, the lack of information about the agrifood nanotechnology research agenda in the US reduce the opportunity of policy debate in regards to the role that public research agenda should follow, in order to diminish potential risks associated with the use of nanotechnology, and guide the research toward those areas in which nanotechnology can increase its contribution to improve productivity in a more sustainable approach. Secondly, due to differences in beliefs and opinions with respect to the real contribution of the use of nanotechnology in the agrifood sector, it can generate the formation of at least two advocacy coalitions, one pro-nano which tries to influence in policy makers to make the biggest efforts to invest more fund without restrictions and regulations, and other group that has more doubts about the real contribution in the application of this discipline in food production. Finally, a third issue that requires a close study is the role that each coalition plays in influencing institutional framework with respect to their set of beliefs. The study of the agrifood nanotechnology research agenda in the last decade in the US is studied in Chapter 4. The presence of advocacy coalitions in the agrifood nanotechnology subsystem is studied in Chapter 5. And finally, in Chapter 6, it is studied the actions that coalitions take in order to influence the research agenda.

2.9 Theoretical Background

The Sectoral System of Innovation from innovation systems and the study of Advocacy Coalitions Framework from the policy process theory are the two theoretical frameworks that ground my research questions. Both frameworks center the research attention in the interaction of the different entities of the systems as unit of analysis. In the first case, the SSI allows to understand the generation, diffusion, and application of knowledge that allocate the growth of a particular sector (Nelson 1993). The ACF helps to understand the reasons by which different actors join in coalitions to influence the policy process and the policy outcomes (Sabatier 1993; Sabatier and Weible. 2007)

The SSI framework is focused in how a determined technology can produce change and transformation inside of the system. This framework offers a clear delimitation of the boundaries of the system in which several actors interact to transfer knowledge and produce the advancement of the industrial sector. The SSI considers three building blocks as key components of the system: knowledge and technology, actors-networks, and institutions.

The agrifood sector is particularly sensitive with respect to the adoption of new technologies, because this sector is oriented to produce food that people consume, it opens the subsystem to more actors, in particular civil society organizations and workers and consumers organizations that believe that have the rights to be informed with respect the consequences from the use of new technologies such as nanotechnology.

The interaction of entities of the innovation system, such as policy brokers, public research organizations, researchers, agrifood companies, environmental NGOs, and consumer organizations compound the unit of analysis. Each entity has its own attributes, for instance policy makers such as USDA, NSF, and EPA are among the main relevant federal actors that shape the nanotechnology research agenda in the US (see Figure 3), contributing with funding nanotechnology research projects conducted in public and private research organizations and setting the regulation framework by which nanotechnology is conducted in the US. For instance the projects financed by the USDA seek to contribute to the achievement of the agency goals of improving crop productivity, food processing, food safety and reducing environmental consequences of food production, storage and distribution. These three Federal agencies are part of the US National Nanotechnology Initiative (NNI) that since 2000 is coordinating the Federal nanotechnology research and development in the US. The NNI first strategy plan considered agriculture as one of its areas where nanotechnology could contribute to the advancement of the sector, highlighting four incipient areas of research, such as (1) molecularly engineered biodegradable chemicals for nourishing plants and protecting against insects; (2) genetic improvement for animals and plants; (3) delivery of genes and drugs to animals; and (4) nano-array-based technologies for DNA testing (NNI 2002).

The USDA has developed intramural and external research programs to achieve their goals and additionally to contribute with the NNI goals for the agrifood sector. NIFA administrate four nanotechnology research grant programs, such as the principal one is the Agriculture and Food Research Initiative (AFRI) foundational program that supersedes the National Research Initiative (NRI) that focus its research area in childhood obesity prevention, food safety, and climate change among others. The Hatch funding another program that has financed nanotechnology research, this program has provided for agricultural research on an annual basis to the State Agricultural Experiment Stations (SAES's).

The EPA has oriented its intramural and external funding research toward environmental applications of nanoparticles that can help to remediate polluted sources in the environment, and also to study the effects of the exposure of nanomaterials in the environment and its potential risks to humans, wildlife, and ecosystems.

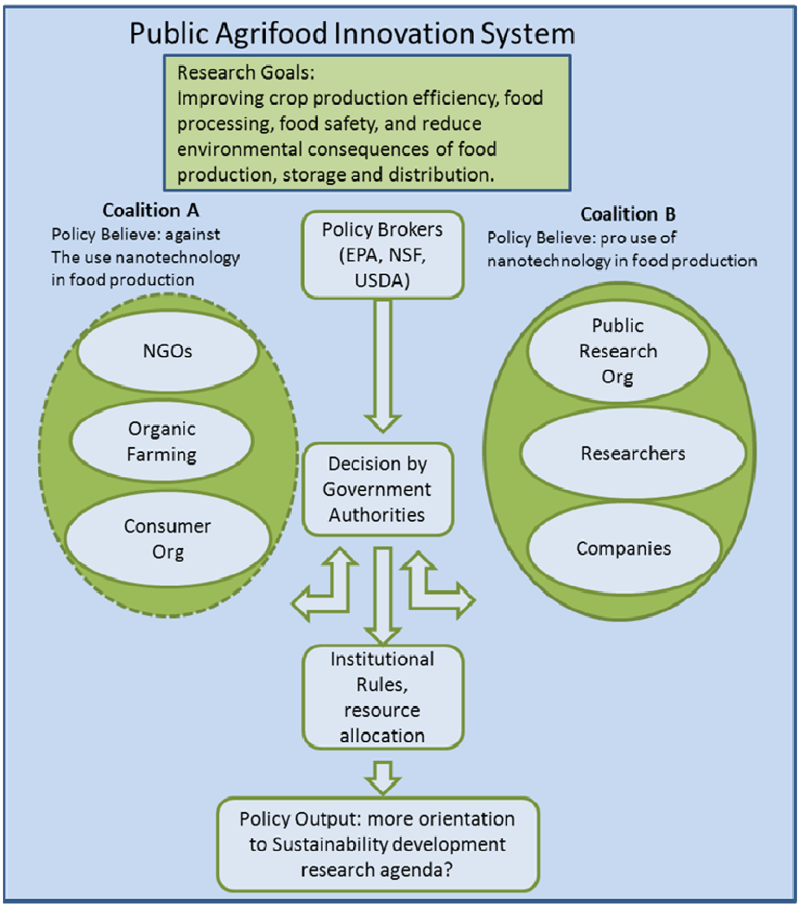


Figure 3: Conceptual Framework to Study the Use of Nanotechnology in the US Agrifood Research Agenda

Researchers are part of an entity that plays a key role in conducting the nanotechnology research, their main attribute is the scientific knowledge that they utilize to the enhancement of the discipline in the agrifood sector. They collaborate with other colleagues inside and outside their organizations to conduct research. These links generate research groups, in which each researcher contributes with particular knowledge, skills, resources, and equipment to apply for Federal agencies funding. Their research goals can differ from those of the Federal agencies. This group of researchers has been direct linked with policy makers in the implementation of the nanotechnology initiative in the agrifood sector since early stage of development, for instance the first workshop conducted by the USDA to elaborate a road map for nanotechnology research in the agrifood sector was integrated in a majority by researchers from land grand universities (Scott 2003).

A third relevant entity is compounded by social organizations, such as non-governmental organizations (NGOs), consumer and workers organizations that have questioned the real benefits from nanotechnology to the food production, and at the same time they have share their concerns respect to potential risks that have been underfunded by federal agencies that support nanotechnology research. These organizations interact in a different manner with Federal agencies, because they are not necessarily looking for research funding, but they are interested in influencing the nanotechnology research agenda and lobbying government, in the manner this agenda affects their interests as few as possible. For example, they can raise awareness about the problem of unintended effects from the use of nanotechnology in the agrifood sector, the lack of institutional framework that can regulate the use of nanomaterials in food processing, the negative effects in health and environment of rural population, etc.(Miller and Scrinis 2010) This entity usually has a more informal type of organization compared with research organizations or agrifood companies, they have less resources and more horizontal organizational structure that reduce their influential power in the agrifood sector. As well as researches, they can join in groups with similar beliefs with respect to the use of nanotechnology in the agrifood sector to advocate for more regulations and influence the research agenda toward more sustainable development issues.

This complexity of the Agrifood sector requires a deep study of the role different actors play in the nano debate. The Sectoral System of Innovation approach used in this research needs to be complemented with the use of the Advocacy Coalition Framework, which is the theoretical framework from policy process useful to study the interaction of these entities, and analyze them in term of interaction among participants that can share a set of common beliefs and arguments that increase the chances to form advocacy coalitions groups in the nanotechnology agrifood policy subsystem, seeking to influence the public research agenda.

2.10 Research Questions

In order to understand the roles played by the different actors in the US public nanotechnology research agenda, it is crucial to focus research attention on the interaction of the different actors, so then empirically demonstrate their association in coalitions, in which they share values and organize collective actions in order to influence the policy process by which the research agenda is conducted. The hypothesis behind this research is that growing level of information and actions taken by advocacy coalitions increase the attention towards sustainable issues in the US public agrifood nanotechnology research agenda. While the ACF has not been applied to the nanotechnology research subsystem before, it has been applied in several other subsystems to study the role that coalitions play to influence the policy process. In a revision of hypothesis tested conducted by ACF authors (Weible 2009)in previous research there was one in particular that it is related to my hypothesis, which is the following one:

“Even when the accumulation of technical information does not change the views of the opposing coalition, it can have important impacts on policy—at least in the short run—by altering the views of policy brokers” (p. 129).

To answer these research questions introduced in Chapter One, I utilized the Sectoral System of Innovation approach which considers: knowledge and technology, actors and networks, and institutions as three key building blocks of the framework. Additionally to the analysis of actors’ interaction in coalitions I utilized the Advocacy Coalition framework from policy process.

2.11 Description of Variables

The dependent variable utilized in this research is nanotechnology research agenda defined in terms of the public agrifood nanotechnology research oriented toward sustainability issues. The agrifood SSI is evaluated respect to three dimension variables in which innovation and learning take place based on a particular knowledge and technology, conducted by actor and networks, and bearing by institutions that set the rule of the game by which the sector is developed. These three variables contribute to delimit the system and focus the research on these three building blocks of the SSI. The ACF framework is utilized to study in more detail the role played by the different actors of the systems, and studies their relationships to form advocacy groups. The three building blocks of the SSI are described as follow:

1. **Knowledge and Technologies**

The unit of analysis is the research field of nano science and its knowledge application through the nanotechnology in the agrifood sector. The selection of nano applications in the agrifood sector requires a deep study of the current scientific literature in order to understand the main areas of research, the technologies in each field, the research foci, and the central keywords to evaluate the US agrifood nanotechnology research orientation in the last decade. The results of this analysis are presented in Chapter 4.

The selection of US agrifood nanotechnology articles contributed to finding the main researchers and their collaborations, information used in the chapter 5 to conduct the interviews with relevant actors of the system. These data source helped me to answer my research subquestion (i).

2. Actor and networks

The bibliometric analysis of the US nanotechnology agrifood publications is used as the source to find main research centers and the researchers that have been contacted in this dissertation to conduct semi-structured interviews with key actors of the nanotechnology research in the US agrifood system (for interview guide see section Appendix A). Additionally to interview with researchers, a revision of relevant documentation and reports has been used to find other actors of the US agrifood nanotechnology sector, such as federal agency managers, and social organizations such as environmental NGOs and worker organizations. The interviews with relevant actors of the agrifood nano system contributed to the deeper understanding of actors' interactions and recognize the existence of coalition groups, their beliefs, arguments, and resources utilized to influence the US agrifood nanotechnology research agenda. This qualitative research method provides a response to my main research question and the subquestion (ii).The result of the presence of advocacy groups through interviews with key system's actors is presented in Chapter 5.

3. Institutions

The interactions of the agrifood nanotechnology actors are shaped by institutions that circumscribe the environment within they interact. In which aspect the nanotechnology research and development has been affected (rather positively or negatively) by the coalitions' actions toward influencing institutions with respect to nanotechnology. This part of the analysis helps to provide a response to the subquestion iii. The results of this analysis are presented in Chapter 6.

CHAPTER 3

DELIMTINGTHE AGRIFOOD NANOTECHNOLOGY SECTOR, RESEARCH DATA AND METHODOLOGY

3.1 Introduction

The US National Nanotechnology Initiative defines nanotechnology as “the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.” (NNI 2011) At this scale, the properties of materials differs respect to their physical, chemical, and biological properties. These unique characteristics open the development of new materials with novelty properties to the agrifood sector. In this research the definition of “sector” is applied by the proponents of the Sectoral System of Innovation theoretical framework, Malerba (2004)defined sector as “a set of activities that are unified by some related product groups for a given or emerging demand and that share some basic knowledge” (p. 9). The dissertation considers the agrifood sector as the conjunction between the agriculture productions with food processing activities. Agrifood is a sector in term of Malerba classification because the agrifood sector uses farm land to produce foodstuff or raw materials used in other industries.

Nanotechnology in the agriculture sector is in an early stage of development, which promises to improve current agriculture practices through the enhancement of management and conservation of inputs in crops and animal production (IFPRI 2011).

Nanotechnology also offers new opportunities to the improvement of food processing with the development of a set of nano-devices tools to improve food quality (Chaudhry, Scotter et al. 2008). This chapter studies the development of the nanotechnology research in the US with respect to the policy context by which the nanotechnology has been promoted in the public agrifood research agenda. This chapter also describes the data utilized in this dissertation and present the methodology utilized in the dissertation to provide responses to the research questions.

3.2 The US agrifood nanotechnology sector

3.2.1 Policy Context of the national nanotechnology research agenda in the US

The first public initiative to promote the research and development of nanotechnology in the US research sector at universities and public research organizations was led by the National Science and Technology Council in 1989, who established the Interagency Working Group on Nanotechnology (IWGN), organization in charged to study the state of the art in nanoscale science and technology and to forecast possible future developments. The IWGN published a report called “Nanotechnology Research Directions: Vision for the Next Decade in 1999. This report laid the foundations for a national strategy plan of nanotechnology R&D and allowed the formation in 2000the U.S. National Nanotechnology Initiative (NNI). This strategy plan emphasized the research orientation in three main areas: developing a balanced research and development infrastructure, advancing critical research areas, and nurturing the scientific and technical workforce of the next century. Promoting an associative work among the relevant actors of the scientific community, federal agencies, and the private sector, and funded with Federal investment[3]

The first federal funding nanotechnology R&D program was launched by President Clinton in the FY2001. Two years later, the US Congress passed the first law to create a constitutional foundation for the activities of the NNI called the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153). Since FY2001 The NNI budget has cumulated $18 billion (including $1.8 billion FY2013 request)[4] to support interagency nanotechnology R&D activities.

3.2.2. Policy Context of the Nanotechnology Research Agenda in the US agrifood Sector

The United States Department of Agriculture (USDA) has been the main federal agencies that pursue the public research agenda in nanotechnology research oriented to agrifood sector. USDA was member of the National Science and Technology Council (NSTC) subcommittee on Nanoscale Science, Engineering and Technology (NSET) since 2001.

Since 2001, The USDA section called the Cooperative State Research, Education, and Extension Service (CSREES) was in charge of the National Research Initiative Competitive Grants Program that started funding individual projects in nanotechnology research in 2001.Two years later the program in Nanoscale Science and Engineering for

[3] Roco, M. C., R. S. Williams, et al. (1999). Nanotechnology Research Directions: IWGN Workshop Report. Vision for Nanotechnology R&D in the Next Decade, DTIC Document.
[4] The National Nanotechnology Initiative "Supplement to the Pesident's 2013 Budget" (Subcommittee on Nanoscale Science, Engineering, and Technology. Committee on Technology, NSTC, Washington DC, 2012)

Agriculture and Food Systems was formally established. In 2008 the Congress signed the Food, Conservation, and Energy Act of 2008 that change the CSREES to a new institution named the National Institute of Food and Agriculture (NIFA). NIFA replaced the former Cooperative State Research, Education, and Extension Service (CSREES) which had been in existence since 1994.

In November of 2002 was held the National Planning Workshop: “Nanoscale Science and Engineering for Agriculture and Food Systems” organized by the USDA/CSREES in Washington, D.C. The main objective of the workshop as the organizers of the workshop Scott and Chen (2003) pointed out was "to develop a science roadmap (strategic plan) with recommendations for implementation of a new program in nanotechnologies in the USDA (as a partner in the federal NNI) for agriculture and food systems”(p. 1). The workshop participants were researchers which work were related with nanotechnology research, administrators from Land Grant Universities and members from other federal agencies, such as the National Science Foundation (NSF) and the Environmental Protection Agency (EPA).The workshop proposed eight main research basic areas necessary to be supported, such as: microfluidics, BioMEMS, nucleic acid bioengineering, smart delivery systems, nanobioprocessing, bioanalytical nanosensors, nanomaterials, and bioselective surfaces. The final recommendation of the USDA/CSREES report was to generate a 15 years roadmap with the establishment of a annual Federal funding source to finance investment in nanotechnology research and enabling technologies for agrifood systems in six strategy research areas, such as: Sensors, Identity Preservation, Smart Treatment Delivery, Smart Systems Integration, Molecular and Cellular Biology, and Materials Science, with a total recommended annual budget of $36.3 million[5](See Table 2).

The USDA/CSREES report that was the first attempt of the policy makers at USDA to establish the research agenda for nanotechnology in the agrifood sector did not consider the aspect of sustainability. Only in Chapter 9 of this report was dedicated to social aspect nanotechnology, which covers ethical issues, and education of the public and future workforce. Including recommendations of research both the benefits and potential risks that should be opportunely communicated to the public, they pointed out this necessity in the following sentences: "We need to avoid the past difficulties encountered with biotechnology and advance a process of public awareness of both positive and negative effects of nanotechnology so that the science may evolve safely and rationally" (pg. 45). Unfortunately most of the activities proposed in this aspect were not carried on further USDA programs due to budgetary restrictions.

Table 2: Recommended USDA Budget Nanotechnology Agrifood Program 2003.

ANNUAL BUDGET RECOMMENDATION	**Million $**
1. **Fundamental Research** (six areas)	4.5
2. **Theme Area Challenge (**Multidisciplinary in the six fundamental areas)	4.2
3. Centers of Excellence (include public outreach)	20
4. Infrastructure	5.0
5. Education	2.6
TOTAL annual budget $Mill	**36.3**

Source: USDA/CSREES, 2002

Nevertheless, an early participation of the USDA in the national nanotechnology

[5]Scott, N. a. H. C. (2003). "Nanoscale science and engineering for agriculture and food systems." Washington, DC: Cooperative State Research, Education and Extension Service, United States Department of Agriculture.

initiative and the establishment of a strategy plan that expected to supply public fund into six fundamental research areas and the formation of 4 regional centers of excellence, which proposed to increase from the $1.5 million fundamental research funding FY2002 up to $36.2 million in FY2003 (see Figure 4). The recommended budget presented by the USDA National planning workshop was neither considered in the FY2003 budget nor in the following years. Instead of that, the NNI supplement to the President's FY2003 Budget presented in June 2002 was taken into account for the definition of the budgetary discussion of FY2003. This document described the intergovernmental initiative and its implementation plan, considering an increase in the USDA annual budget oriented to nano-biotechnology up to $2.5 million. This early report reduced the scope and goals defined by the group of researchers and agencies that participated in the first national workshop planning document presented later that year.

The NNI technical report identified impacts and application of both nanotechnology and biotechnology in the agriculture sector, proposing research orientations toward biosynthesis and bioprocessing to manufacture new chemicals and pharmaceutical products. The report recommended promote fundamental research in biology integrated with synthetic materials and devices to generate new material that imitate the biological systems that can contribute to the advancement of the agriculture sector. The NNI report mentioned four areas of research: "Nanoscience will contribute directly to advancements in agriculture in a number of manners: (a) molecular-engineered biodegradable chemicals for nourishing plants and protecting against insects; (b) genetic improvement for animals and plants; (c) delivery of genes and drugs to animals; and (d) nanoarray-based technologies for DNA testing[6]" (p. 15).

In 2004, another unit of the USDA started to plan a research program in nanotechnology. With a workshop title "Nanotechnology for the Forest Product Industry" led by the Forest Service, and with similar approach from the previous workshop organized by USDA/CSREES, but with two main differences, the workshop included international participants, such as university researchers, industry members and government laboratories. A total of 110 participants from North America and Europe attended to the workshop. In this workshop nanotechnology was presented as a research area that can increase the benefits of the sector, as was written in the report "Nanotechnology can be used to tap the enormous undeveloped potential that trees possess—as photochemical "factories" that produce rich sources of renewable raw materials using sunlight, water, and carbon dioxide. By harnessing this potential, nanotechnology can provide benefits that extend well beyond fiber production and new materials development and into the areas of sustainable energy production, storage, and utilization[7]". The workshop described six research areas in which nanotechnology could make a big contribution, such as polymer composites and nano-reinforced materials, self-assembly and biomimetics, cell wall nanotechnology, nanotechnology in sensors, processing, and process control, analytical methods for nanostructure characterization, and collaboration in advancing programs and conducting research. The vision of the roadmap was explicitly oriented to sustainable development, such direction was described in the report "To sustainably meet the needs of present and future generations

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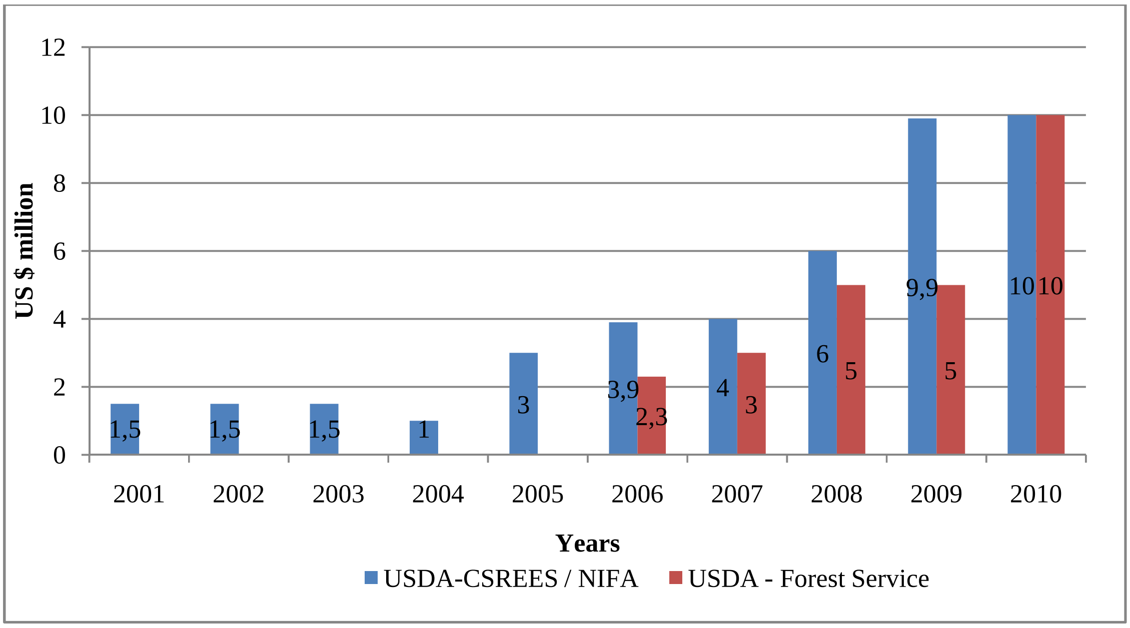
[6] The National Nanotechnology Initiative "Supplement to the Pesident's 2003 Budget" (Subcommittee on Nanoscale Science, Engineering, and Technology. Committee on Technology, NSTC, Washington DC, 2003)

[7]Nanotechnology for the Forest Product Industry: Vision and Technology Roadmap " USDA Forest Service, October 2004.

for wood-based materials and products by applying nanotechnology science and engineering to efficiently and effectively capture the entire range of values that wood-based lignocelluloses materials are capable of providing." (p. 7) the roadmap proposed to have a budget for the forest product industry of about$40 to $60 million per year starting in 2008. But as well as the NIFA the final annual federal budget was only about $5 million in 2008.



Source: NNI Federal budget 2000-2010

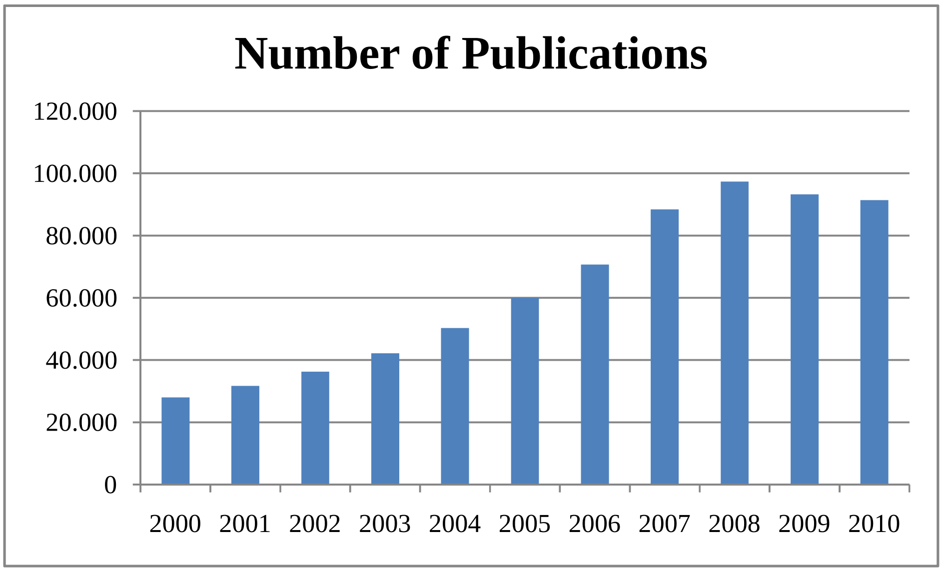
Figure 4: USDA Annual Budget for Nanotechnology Research Period 2001-2010

The Public support of the US agrifood nanotechnology research since a decade ago has played a crucial role in shaping the innovation process in this sector. In order to know which research areas have received more attention by universities researchers, and if sustainability issues have been part of this research orientation it is important to conduct a bibliometric analysis of the research publications in the period 2000-2010. This analysis can allow observing how the nanotechnology agrifood sector has evolved since the first public support and was established and which actors are the most relevant with respect to research and what kind of collaborations they have developed during this period (for a complete description of the methodology used to select the agrifood nanotechnology articles please see the section 3.5). Furthermore, to get a more profound understanding of the process by which the public nanotechnology research agenda has been established and developed, a qualitative analysis which includes a study of relevant documentation and semi-structure interviews with members of research organizations, policy makers, and social actors is required. In the following sections of this chapter a complete description of data and methodology utilized in this research are presented.

3.3 Data

The dissertation considered a mixed method analysis. First, I used a bibliometric database of world nano-publications for my quantitative analysis of the US agrifood nanotechnology development in the last decade. This analysis was complemented with a qualitative analysis that considered semi-structured interviews with key actors of the agrifood system, additionally, I collected and analyzed secondary information sources, such as congressional hearings related to nanotechnology in the US, federal agencies public hearing and official reports published during the last ten years. Finally, to select and study the social organizations that participate in the agrifood nano-debate, I collected their organization information provided in the internet web pages. These three data sources: research publications, semi-structured interviews, and official reports and organizations' web pages were the main source of information to characterize the US agrifood nanotechnology system, and study the public research agenda. The detailed description of the data is presented in the following section.

I characterized the agrifood nanotechnology in the US with the use of the CNS-ASU nanotechnology bibliometric data set 2000-20010 developed by researchers at Georgia Tech (Porter A, Youtie J et al. 2007; De Bellis 2009) as part of their work with the Center for Nanotechnology in Society at Arizona State University (CNS-ASU). This dataset is comprised of nanoscience and nanoengineering articles indexed in the Web of Science/ Science Citation Index. This is an international authorship database, so then I only considered those articles that included at least one author who has been affiliated to an organization with address in the US. During the last decade a total of 689,633 articles in all areas of research were collected in the CNS-ASU dataset, with an average annual growth of 13% (see Figure 5). The 2009-2010 data were collected with a different filtering strategy than the previous years. This new filtering strategy was developed by the same team that developed the filtering strategy for previous period 2000-2008, and considers an upgraded version with more accuracy in finding the key words that are related almost exclusively with nanotechnology research. For instance, in the first version some inaccuracies were observed with the inclusion of the word “molecule” that not necessarily needs to be related with nanotechnology. This change in the filtering strategy made a slightly reduction in the total number of nanotechnology paper collected and it not necessarily represent a slowdown in the number of total nano publications for the last two years.



Source: CNS-ASU dataset, 2012

Figure 5: Number Publications CNS-ASU Nanotechnology Bibliometric Dataset Period 2000-2010

To retrieve the articles in the agrifood sector, I developed a search strategy through several steps. First, I examined review articles to understand the main technologies and research foci in the agriculture and food processing sectors (agrifood). Using the language of the review articles, I chose initial keywords to represent each sector, technology, and focus, and built filters to locate articles in the larger nanotechnology database that carried those keywords. After the initial search, I continued to refine the search terms through iterative bootstrapping. The bibliometric analysis helped to characterize the agrifood nanotechnology research agenda, and the dynamic in the last decade with respect to the categories, researchers, and areas of research that are related with sustainability issues.

After that I filtered the nanotechnology papers related exclusively to agriculture and food sector through a filtering process that considered keywords that help me to include those papers in which the keyword was mentioned either in the title, author keyword, and abstract section of each articles. This field in the Vantage Point software receives the name “Combine keyword + Phrases” (See Appendix B: Keyword strategy search). Once I obtained my US agrifood nanotechnology database I required to clean from the data those articles that in spite of they coincide with at least one of the keyword strategy search data, but it was not directed related to the agrifood sector. For example, one persistent case that required a close revision occurred with nanotechnology papers that have the word “soil” in their combined keyword + phrases searching, because in some few cases (5) were articles oriented to astronomic research of lunar or Martian soils.

Additional to the filtering strategy described before, I considered the definition with three dimensional criteria utilized by the US National Nanotechnology Initiative. These three criteria help to delimit the scope of nanotechnology research articles in my methodology to make a more accurate papers selection. This was necessary because I found in my data analysis that the CNS-ASU bibliometric dataset 2000-2010 presented few mistakes with respect to its own thesaurus editor strategy. For instance, after I selected my US agrifood dataset I realized that some articles that showed up in the field of nanotechnology not necessarily fulfill the three NNI criteria to consider a research as nanotechnology. Which are the following:

1) Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1-100 nanometer

range (Committee for Review of the Federal Strategy to Address Environmental, Materials et al.).

2) Creating and using structures, devices, and systems which unique phenomena enable novel applications in the agriculture or food sector.

3) Exploiting functional physiochemical properties to produce nanoparticles able to control or manipulate on the atomic scale.

In order to test if the selected papers fulfill the three criteria definitions it was essential to read each paper abstract of the US database to find which are not compulsory with nanotechnology matter, because the CNS-ASU database search strategy presented some spurious non-nano records. For example, some papers which considered the word "molecular" more related to biotechnology than to nanotechnology research. After the filtering and data cleaning I end up with a dataset of a total 1,140 scientific articles that I used in the analysis stage with the utilization of Vantage Point data mining software.

Additionally to the quantitative analysis of nanotechnology publications, a qualitative analysis was conducted, which utilized secondary sources of data to determine actors of the US agrifood systems. Nanotechnology research is characterized by a weak flow of information of research issues to the public, the lack of information can produce more controversy about potentially negative effects of the use of nanoproducts in food (Yawson and Kuzma 2010). Therefore, I complemented the bibliometric analysis with the Advocacy Coalition Framework to obtain a deeper understanding of the policy process by which the agrifood nanotechnology research agenda is established and see the role each actor plays in each coalition. It was required to conduct interviews with actors that represent all the interest groups in this system. I conducted interviews with 24 relevant actors of the system selected from four sources:

1. Bibliometric analysis (CNS-ASU bibliometric dataset 2000-2010)
2. List of nano focus NGOs in the US (Lee and Kigali 2006), complemented with internet searching.
3. The use of the USDA CRIS database and the NSF awards, both free available in internet (http://cris.nifa.usda.gov/ and http://www.nsf.gov/awardsearch/), using nanotechnology as keyword, which in 2005 was utilized by Kuzma, J. and P. VerHage (2005) who found 90 USDA and 35 NSF projects of agrifood nanotechnology in period 2000-August 15, 2005.
4. List of actors obtained from the public hearing documentation (see Table 3 for more details).

After conducting the of agrifood nanotechnology actors search strategy I found a total of 22 social organizations, 17 federal agency managers, and more than 100 researchers.

The list with contact information of social organizations and federal agency managers was stored in a Microsoft Excel file, later on I located the personal information as name, position and email address of each policy analysts and agency officials in each organization websites, with the goal to take a further contact through an email to invite them to participate in a research interview, just after I have concluded the Institutional Review Board (IRB)protocol to conduct the semi-structured interviews. In this case the interviews represented a very low risk for interviewees because the interview questions were oriented to ask about organizations issues and not personal questions. After the IRB protocol was approved I started to contact people from my list to ask for the semi-structured interviews, which were recorded, transcript and collected in a safe file for further analysis with respect to advocacy coalition framework.

This group of actors were chosen because they are direct related with nanotechnology research agenda, for instance policy makers are who have organized workshops with researchers in order to define roadmaps, research goals, areas of research, and emphasis respect to their own agency goals. Also these federal agency managers are in charge of the program calls for funding, evaluate the results, present the results to the Congress in order to allocate resources for further funding programs.

In the case of researchers, I had a big number of potential candidate (more than 100) to be interviewed, but in this case due to geographical dispersion and constrain in time and resources, I decided to select university researchers located in five regions: South-east (the State of Georgia and neighbor states), researchers located in the South Central, Mid-Atlantic region (DC and surrounding), Upper Midwest, and finally some representative of the West-coast region of the US (California) (see Figure 6).

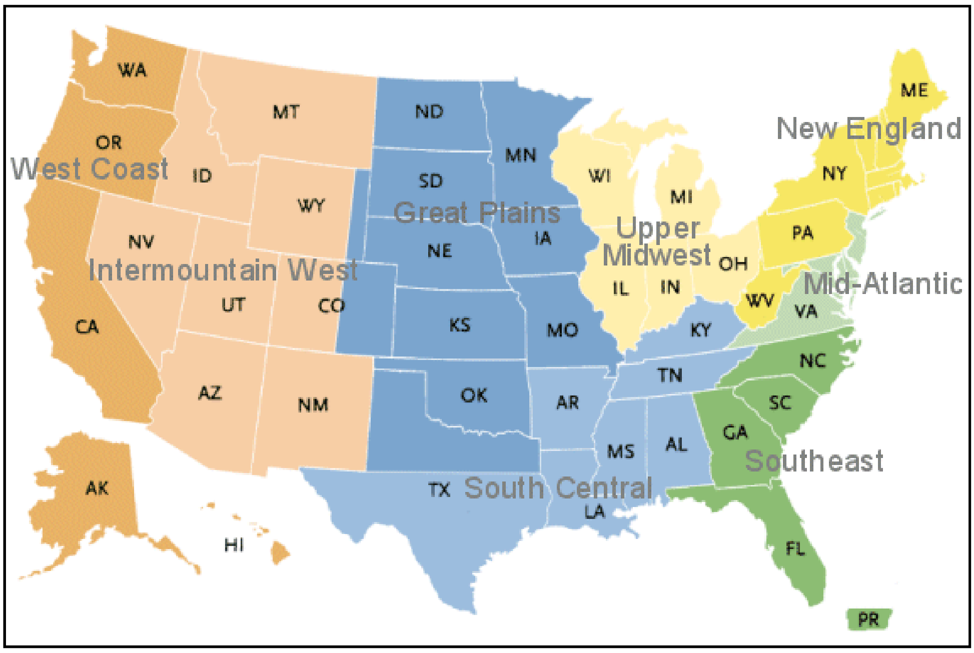


Figure 6: Geographical Distribution of Interviewees

Table 3: Interviews Nanotechnology Agrifood Sector in the US

N°	Organization	Type of organization
1	USDA Forest Service	Federal Agency
2	Economist Economic Research Service, USDA	Federal Agency
3	National Organic Program U.S. Department of Agriculture	Federal Agency
4	Center for Food Safety – International Center for Technology Assessment (ICTA)	NGO
5	AFL-CIO	Worker Union
6	US EPA, ORD, NCER	Federal Agency
7	NSF	Federal Agency
8	BCTGM Intl. Union	Worker Union
9	Friend of the Earth	NGO
10	UGA	Researcher
11	UGA	Researcher
12	Auburn Univ	Researcher
13	Univ Cornell	Researcher
14	Univ Maryland	Researcher
15	UGA	Researcher
16	NRDC	NGO

17	IFPRI	International Organization
18	USDA NIFA	Federal Agency
19	Cornell Univ	Researcher
20	Cornell Univ	Researcher
21	Univ Illinois Urbana-Champaign	Researcher
22	Univ Illinois Urbana-Champaign	Researcher
23	ETC	NGO
24	Univ. California Davis	Researcher

Finally, the third data source used to evaluate the role played by each coalition in influencing the policy process in the development of the nanotechnology in the agrifood sector in the US system, through a literature review of relevant documents related to the development of the nanotechnology research agenda in the US (see Table 4), complemented with Congressional House Hearing conducted the last 10 years.

Table 4: Official Documentation Related to Nanotechnology

Documents
1. National Nanotechnology Initiative Amendments Bill (2009)
2. Twenty-First Century Nanotechnology Research and Development Act
3. Toxic Substances Control Act. (TSCA)
4. The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues
5. The Federal Insecticide, Fungicide and Rodenticide Act, or FIFRA.
6. S. 2942 (CONGRESS)—Nanotechnology Safety Act of 2010
7. Federal Food, Drug, and Cosmetic Act (FD&C Act)
8. Nanoscale Materials Stewardship Program EPA
9. Report: Nanoscale Science and engineering for Agriculture and Food Systems USDA 2003
10. Nanotechnology Research Directions IWGN Workshop Report (1999)

11. Nanotechnology Research Directions for Societal Needs in 2020 (NNI, 2010)
12. EHS Research Strategy (NNI, 2011)
Congressional House Hearing (CHH)
13. 106th CHH: nanotechnology: the state of nano-science and its prospects for the next decade
14. 109th CHH: Nanotechnology: where does the U.S. stand?
15. 109th CHH: research on environmental and safety impacts of nanotechnology: what are the federal agencies doing?
16. 109th CHH Environmental and Safety Impacts of Nanotechnology: What Research is needed?
17. 110th CHH: research on environmental and safety impacts of nanotechnology: current status of planning and implementation under the national nanotechnology initiative research on environmental and safety impacts of nanotechnology
18. 110th CHH: National Nanotechnology Initiative: Charting the course for reauthorization
19. 110th CHH: the national nanotechnology initiative amendments act of 2008
20. 111th CHH: The Transfer of National Nanotechnology Initiative Research Outcomes for Commercial and Public Benefit
21. 112th CHH: Nanotechnology: Oversight of the National Nanotechnology Initiative and Priorities for the Future

3.4 Research Design

The dissertation utilized a mixed method, which included a bibliometric analysis, interviews with relevant actors of the system, and analysis of official documentation of the regulatory framework and nanotechnology reports of the US agrifood nanotechnology system. These three sources of information are utilized for the research in a case study design, which is appropriate for studying because achieve the three conditions(Yin 2008) to best applied case study research:

1. The form of the research question seek to posed how, why? questions which are of the type explanatory, that deal with question that are connected with events that occur over a time frame.

2. Extent of control over behavioral events, in which the behaviors cannot be manipulated, and require a direct observation of the events and interviews with persons involved in the events.

3. Focus in contemporary events.

My research seeks to understand how much attention the US public nanotechnology research agenda pay to sustainable development. To investigate this question I utilized a mixed method analysis that considered bibliometric analysis and semi-structured interviews with key actors that currently are involved in the nanotechnology debate to study their interaction in advocacy groups to influence the nanotechnology research orientation in relation to sustainability issues.

3.5 Techniques of Analysis

Once I obtained my final cleaned dataset with the US agrifood nanotechnology articles (2000-2010), I used a similar approach to classify the nanotechnology research in eight topics developed by the Project of Emerging Technologies (Kuzma, VerHage et al. 2006). I made minor updates to the 2006 inventory nanotechnology research topics which were divided into two different categories, the plant and animal production. Additionally in the first case I included those articles that considered nanobiotechnology and in the second I merged the animal production with veterinary product topics due to they are more closed in a similar research discipline. The proposed eight agrifood nanotechnology topics that are presented as follow:

1. *Biosensors:* use of nanotechnology for sensors based upon biological processes or biological molecules, or for detection of biological molecules, processes, or organisms.
2. *Environmental processing*: use of nanotechnology for studying environmental phenomena, removing contaminants in the environment, or remediating/reducing waste, in addition to studies of nanomaterials behavior in the environment.
3. *Sustainable agriculture:* use of nanotechnology for reducing agricultural inputs or outputs that can harm the environment or human health (e.g. pesticides) or are in short supply (e.g. water); or for making products from agriculture in a sustainable way.
4. *Pathogen detection:* use of nanotechnology to detect pathogens in surroundings, organisms or food.
5. *Plant Production/ Nanobiotechnology*: use of nanotechnology to improve the cultivation of plants including via transgenics or cloning.
6. *Veterinary medicine/Animal production:* use of nanotechnology to improve animal health and/or the safety of animal derived foods.
7. *Bioprocessing for food*: use of nanotechnology for better food processing or quality.

8. *Nano-bioindustrial products:* use of nanotechnology for developing industrial products from agriculture or its by-products.

To conduct the classification process I used the keyword strategy process but in this case to obtain more accurate results it was necessary to read each paper abstract of the US agrifood nanotechnology dataset in order to reduce mistakes in classification utilizing only the keyword strategy. In some cases articles fitted in more than one classification, for example in the case of articles that were classified as environmental processing also were included in the biosensor group because of the research used biosensors to solve environmental problems. To measure the evolution of agrifood nanotechnology research with respect to sustainability issues, I selected those papers from topic one to three as proxis for articles that focus their research towards sustainability issues and I measure the number of publication by year to see the trend in publication. If I observe more publications in these three areas over time, then I should confirm that the US agrifood nanotechnology research agenda is moving toward sustainability issues.

After concluding the classification of articles in the eight categories, I utilized the Vantage points functions “cross-correlation maps”. The function cross-correlation maps are graphical representations of the relationship between two different fields, in this case between author affiliation and keyword and phrases. The representation that is obtained from this function shows the network of research collaborations in each of the eight research topics previously described. The results of this work are presented in Chapter 4 of this dissertation.

The research goal of using the semi-structure interviews is to complement the bibliometric analysis in regards to learn from primary source the role of each coalition plays in the public nanotechnology research agenda. The questionnaire (See Appendix A for more details about the questions) was prepared with slight differences' depending on who was the interviewee, divided in to three groups: policy makers or agency managers, researchers, and social actors. This methodology seeks to study the presence of advocacy coalitions, the set of beliefs that maintain the coalition's member unified, the dynamic and collaboration among members related to the research agenda and indirectly observe if the concept of sustainability was part of the argument used by them when they make their arguments to influence the policy process.

The interviews were voice recorded and transcript in a word processor, then each document was stored in a Nvivo 9.2 Software file for the qualitative analysis of data collected, in which the documentation was organized in nodes with respect to the opinion expressed by the participants referred to the agrifood nanotechnology linked to sustainable issues, the entities (actors), attributes (beliefs, arguments, and resources) and their relationships (coalitions), their connection to the agrifood nanotechnology research agenda setting in the US and its contribution toward a more sustainable development. The result of ACF analysis is showed in Chapter 5.

Finally, a set of legal documentation and governmental reports were also analyzed (see Table 3) with the Vantage Point data-mining software to study the actions taken by each coalition presented in Chapter 5, analyzing their performance in Congressional and Federal agencies public hearing and reports in regards to agrifood nanotechnology research agenda. And to see if sustainability is an issue of concern when they argue about nanotechnology research. The results of this methodology are presented in Chapter 6 of this dissertation.

3.6 Advantages and Limitations of the Data and Methodology

The CNS-ASU bibliometric dataset is an important source of information respect to global publications in nanotechnology, which analysis is simplified with the use of the data-mining software. But it is not 100% accurate, and it needs to be revised periodically in order to incorporate new keywords that appear with new applications of this emerging technology. This database utilized a strategy of filtering that was developed early in 2006 and applied for publications from 2000-2009 (with partial coverage of 2009). During my dissertation I revised its searching strategy in relation to agrifood nanotechnology terms and I suggested some modifications in the strategy, which were included in a new period (2009-2010) showing some changes when they were compared. The new strategy reduced the total number of publications, due to a more accuracy in keyword applied to the selection of papers that fulfill the criteria to be considered nanotechnology and excluding those articles that in the first database (2000-2009) included some biotechnology publications as nanotechnology research. Unfortunately, at the time I conducted my bibliometric analysis it was not possible to the researchers in charge of develop the database to make an update of the strategy applied for the previous period of time (2000-2009).

Another limitation produced with the bilbiometric analysis is that the information obtained from it is restricted to the analysis of articles' text from title, summary and keywords. This information offers a good proxy of the research but it does not allow analyzing other sections of the scientific articles that could offer more relevant information, results of the research and applications.

Hence, to diminish this limitation in my research, I considered a mixed method analysis that incorporate semi-structured interviews with researchers from whom I obtained more detailed information respect to their research goals, beliefs, and vision related to nanotechnology development in the agrifood sector. During the semi-structured interviews of about an hour of duration with key actors allowed me to gain deeper understanding of the phenomena that I seek out to research, which was the formation of coalitions and how they influence the public research agenda in nanotechnology research.

The methodology applied to select the potential candidates to participate in my interviews also presented some limitations that are required to take into account. For instance, I found a higher number of potential participants to who I contacted asking for an interview, but in the end not all them replied to my invitation to participate in this research (6 of 22 of social organizations, and 6 of 17 federal agency managers accepted participate). This could produce some bias or lack of information respect to all the actors involved in the agrifood nanotechnology sector. But I tried to at least conduct interviews with the more relevant actors, which I achieved with exception of not getting an interview with any of the managers at FDA agency. In the case I did not obtained a positive response from an organization that I consider relevant, I tried to obtain their information through other members of the coalition that accepted my invitation.

CHAPTER 4.

THE US AGRIFOOD NANOTECHNOLOGY:KNOWLEDGE AND TECHNOLOGIES

4.1 Introduction

The nanotechnology research in the agrifood sector is in a more new stage of development in regards to other research areas. However, it has been constantly growing in the last years, showing a market size estimated in about $2.6 billion in 2006, with a potential increase up to $20.4 billion dollar in 2015(Helmut Kaiser Consultancy 2004).

In the US, since the first workshop in agrifood nanotechnology in 2002, the research area has received more attention and funding to conduct the strategy plan established in 2002. This chapter shows the results obtained from the bibliometric analysis of the United States agrifood nanotechnology research sector in the period 2000-2010. The quantitative analysis of research publication helps to identify the more predominant research areas and its change during the last decade, the organizations involved in conducting the research, the researchers and their collaborations established, and study if the concept of sustainability has been part of the US agrifood research agenda along this period of time.

4.2 The US Agrifood Nanotechnology Research Sector

The US agrifood sector has been leading the research in nanotechnology since more than a decade ago. The National Nanotechnology Initiative (NNI) is a US intergovernmental program that establishes strategy plan and coordinate the work of different agencies in relation to nanotechnology research and development. In the agrifood sector the Department of Agriculture (USDA), the National Science Foundation (NSF), and the Environmental Protection Agency (EPA) are among the most important government agencies that guide their institutional efforts toward agrifood nanotechnology. These interagency initiatives have coordinated the agency's goals and nanotechnology research directions, programs and budgetary aspects, in both the US university system and the research conducted in house research units, such as the USDA's Agricultural Research Service (Kuzma, VerHage et al.). The systematic research funding system in the US has the agrifood sector become world leader in nanotechnology research with about 21% of the global publications (see Figure 7). In 2000 year, the world publications about nanotechnology in agrifood were about 145,in which 35 (23%) of them involved at least one US research organization. After a decade of public support to nanotechnology research in the agrifood sector in several countries of the world, leaded by the US, and followed by China, Germany, and France, the development of the research areas has grown 7.5 times up to 1,096 global publications in 2010, from where 21.2% were published by a US research organization, which represented a 6.8 time higher US publication respect to 2000.

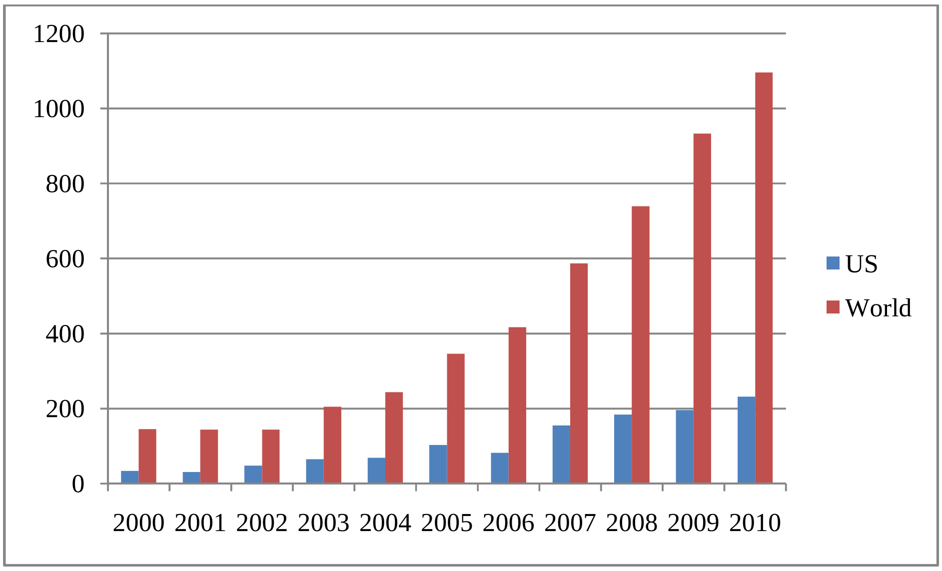


Figure 7: US and World Trend in Agrifood Nanotechnology Publications Period 2000-2010

The first half of the decade the world publication rate in agrifood nanotechnology has grown to 200%, speeding even more the rate of growth up to 300% in the second half of the decade. The high-speed increase in world's publications in this area is explained basically by two actors, the US and by the explosive increase in publications made by Chinese research organizations in the second half of the 2000 decade (see Figure 8).

Meanwhile, between2000 and 2005 the US agrifood nanotechnology research grew higher than the world performance with a rate of growing of 300%. During the second half of the decade the US had a performance less than the first one, with a rate of growing of about 200% in term of number of publication.

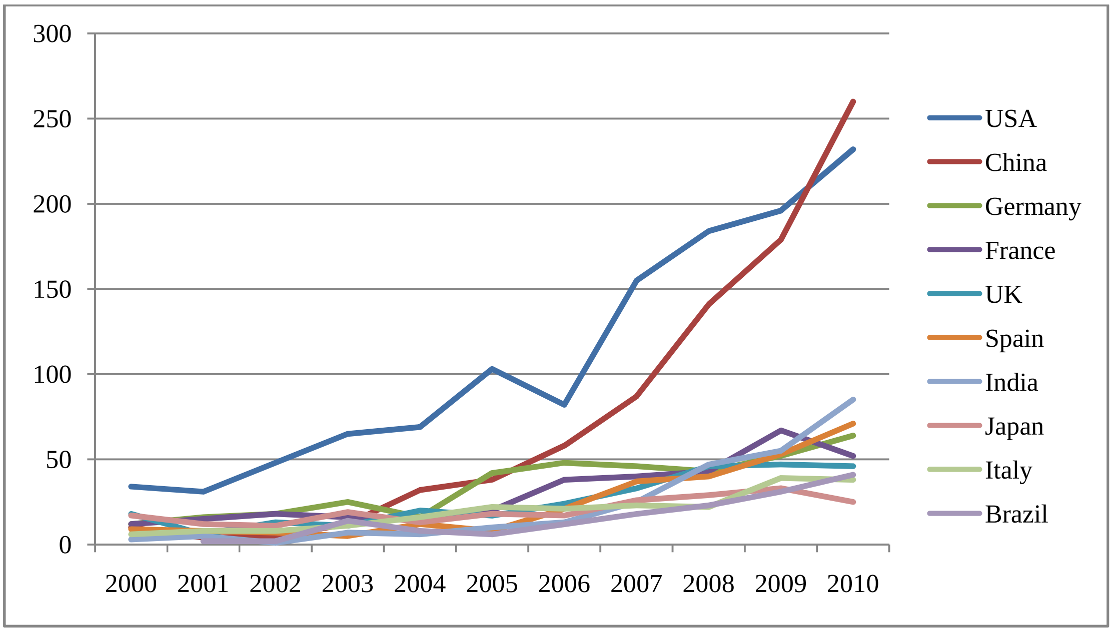


Figure 8: Trend in Agrifood Nanotechnology Publication by Country Period 2000-2010

Agrifood nanotechnology research publications represent only a very small portion of the total US nanotechnology publication. Nevertheless, the number of publications in agrifood nano has been increasing constantly during the last years. For instance, in 2000 agrifood nano-publications represented only 0.3% of total US nano publications, in 2010 agrifood nano-publications grew by four time up to represent 1.2% of total US nano publications (see Figure 9).

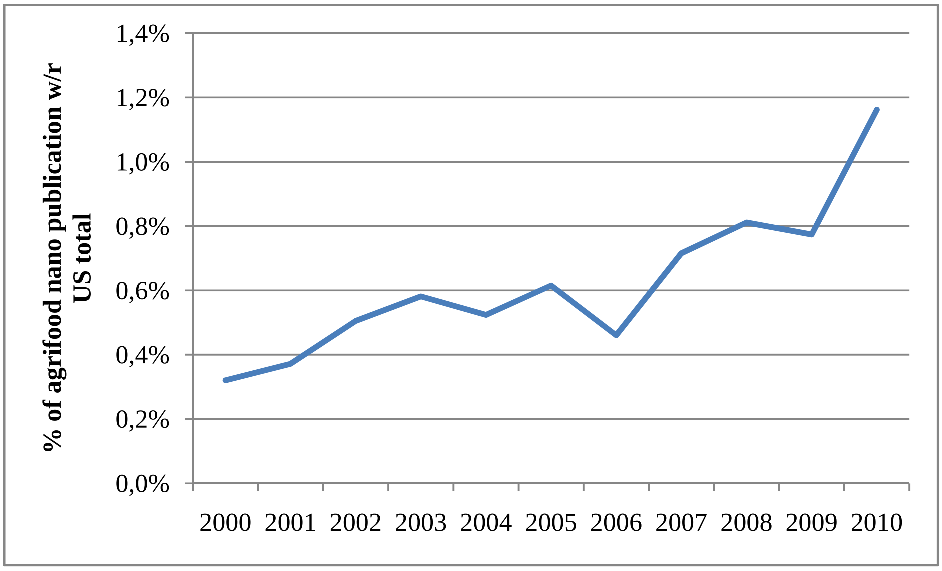


Figure 9: Rate of growth of Agrifood nanotechnology Publications in relation to Total US nano Publications Period 2000-2010

4.2.1 Actors and Research Collaboration

The IWGN Workshop Report "Nanotechnology Research Directions: Vision for Nanotechnology R&D in the Next Decade" published in 1999 (Roco, Williams et al. 1999) was the first official document that pointed out the need for a national nanotechnology research program to achieve the potential benefits observed from the nanotechnology in the agrifood sector. This report laid the foundations to the establishment of the public research agenda in the US agrifood sector. Later on 2002 the USDA organized the first workshop to design the research roadmap in agrifood nanotechnology. This activity was organized by agency officials and researchers that together recognized the opportunity that opened invest in nanotechnology research to produce a positive impact in the sector. Since then, university researchers, federal intramural researchers, and agency official have occupied a predominant place in the agenda setting, and conducting collaborative research. The scientific community oriented to nanotechnology research in the US agrifood sector is compound for several universities and some intramural researchers on federal agencies, such as EPA, FDA, and mainly from the USDA Agriculture Research Service (Kuzma, VerHage et al.) which occupied the top one position with 53 publications among research organizations that publish scientific articles in topics of agrifood nanotechnology. The other top research organizations are Cornell University with 42 publications and University California Berkeley (see table 4). These research organizations in general work in collaboration with other research organizations to publish in scientific journals (see Figure 9).

Table 4: Top 15 US Research Organization in agrifood nanotechnology 2000-2011

Top 15	Research Organization	Number of Publications
1	USDA ARS	53
2	Cornell Univ	42
3	Univ Calif Berkeley	32
4	Univ Illinois	30
5	Univ Texas	30
6	Univ S Carolina	29
7	Michigan State Univ	28
8	Univ Calif Riverside	28
9	Auburn Univ	27
10	Penn State Univ	27
11	Univ Calif Davis	26
12	Purdue Univ	25
13	Univ Calif Los Angeles	24
14	Univ Florida	24
15	Pacific NW Natl Lab	22

In general these research organizations work in collaboration with other research organizations to publish articles in scientific journals. In figure 10, I show a graphic representation of two factors from the bibliometric analysis. Utilizing Vantage Point data-mining software I produced a cross-correlation map between the combine keyword and phrases and author affiliation to see what US research organizations have been involved in the research agenda during the last decade. The figure shows more than hundred research organizations that have participated in agrifood nanotechnology research. Most of them are universities with tradition in studying agriculture and food disciplines, such as Cornell, Purdue, UC Davis, Iowa State University, University of Georgia, among others.

Additionally to the universities research centers, two federal agencies organizations show up in the research system, The EPA and the USDA Agriculture Research Service, both agencies have annual budget to conduct intramural research, as well as funding programs to support external research. This type of financial support for research in agrifood nanotechnology sector has promoted the formation of research collaborations among research organizations. This integration in research clusters made the system quite stable over time, with group specialization in specific research topics, the characteristics of research actors involved in each of the eight nano-research topics that were described in the methodology section of this dissertation will be analyzed with more detail in this chapter.

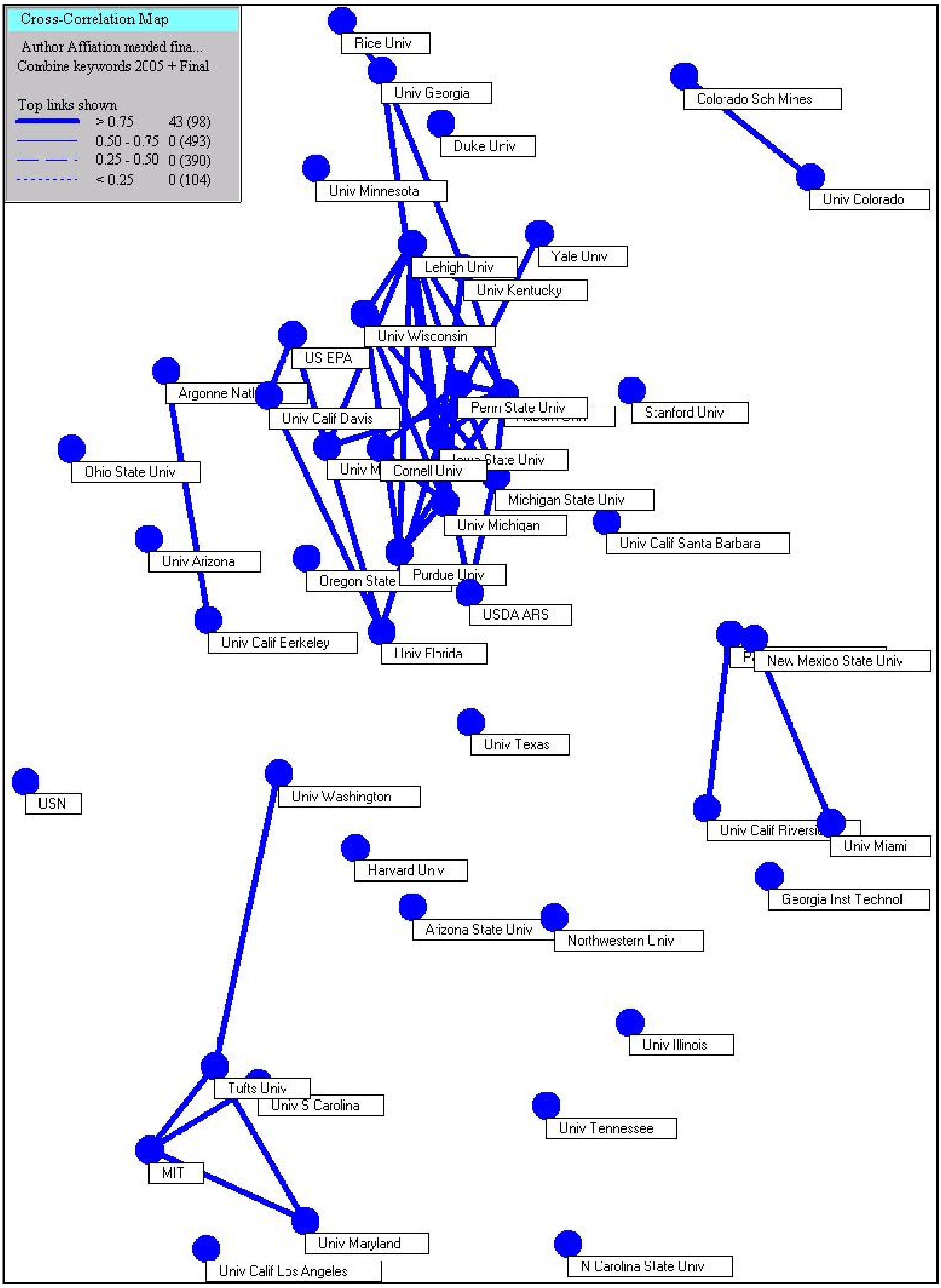


Figure 10: Cross correlation map of US Research Organizations Period 2000-2010

4.2.2 Bibliometric Analysis of the US Agrifood Sector

One of the relevance aspects of this research is to determine the change over time of the US agrifood nanotechnology research agenda and the link with sustainability issues. The Bibliometric analysis primarily focused its attention in establishing what are the main terms used in the US nanotechnology articles from the agriculture and food processing. These two economic activities merged in the concept “agrifood” that was taken from the Sectoral System of Innovation approach described in the literature review section. Therefore, I used these two main concepts “agriculture” and “food” to evaluate the performance in nanotechnology publications, the results are shown in Figure 11. In which it is observed a predominance of nanotechnology publications oriented to agriculture activities, with six articles in 2000 and reaching their highest number of 34 articles in 2008 and a progressive reduction in the following two years. A different trend is observed for papers that study application of nanotechnology in food. Which started to register publications in 2003 and it has increased the number of publications especially after 2007. In 2010, the scientific papers related to food nanotechnology almost reach the same level of agriculture nanotechnology publications. This predominance of papers related to food production during the last years in the US agrifood nanotechnology research has direct relationships with the research orientation in federal agencies toward mainly food safety issues. For instance, the USDA NIFA has promoted research funding in food safety aspects since 2006.

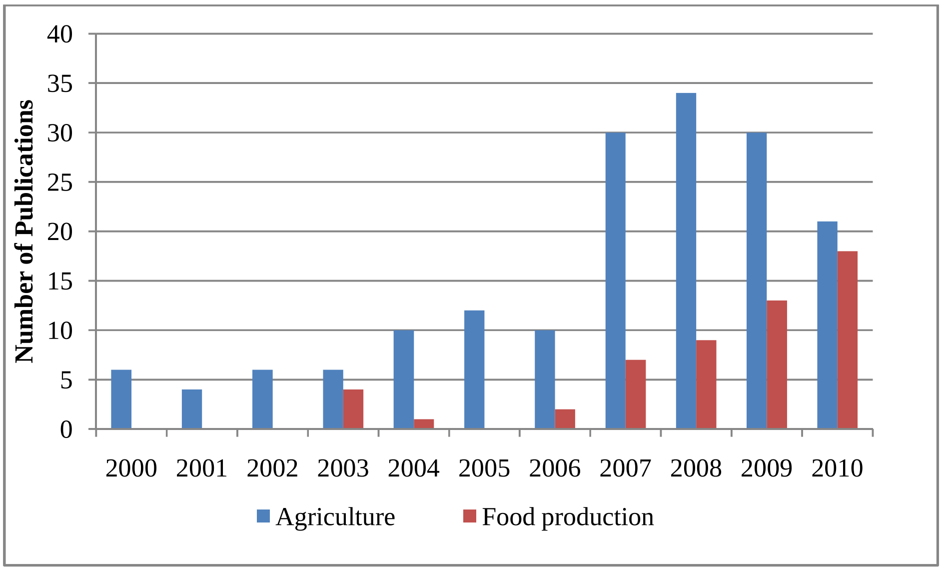


Figure 11: Main Concepts results of the US Agrifood Nanotechnology sector Period 2000-2010

The bibliometric analysis of nanotechnology articles in the US agrifood sector revealed a prevalence number of articles related to soil issues as the most important ones. This research area has experimented increased rate of growth during the last decade, which in the end of the 2010' grown by 500% respect to the same type of research at the beginning of that decade. Soil nanotechnology investigations were mainly focused on environmental aspects, for example articles that study the effects of nanoparticles such as carbon nanotubes in the soil, its bioavailability, toxicity effects, and contaminant soil remediation are among the type of research that used the keyword soil in their articles.

These types of research that incorporate the keyword "soil" not necessarily is about agriculture soil, but these type of research could eventually impact positively in agriculture soil remediation, with the utilization of the technology applied in other non-agriculture soils.

In a second order of importance articles which used keywords such as insecticides, and pesticides were placed. They have in common, the use of nanobiosensors to detect chemicals used which produce severe environment problems as a result of agriculture activities in US agrifood sector.

At less level of importance the research that considered Tobacco Mosaic Virus (TMV)was placed. The TMV is a plant virus, which is used as building template for production of nanomaterials. Biological organisms as virus are particular sources of research interest, due to their characteristics such as, small size, uniform structure, good quality to self-assemble, and high resistance to extreme conditions of pH and temperature. These characteristics have made TMV an efficient nanodevice to be applied in nanoelectronic and nanosensor manufacturing(Steinmetz and Evans 2007). Finally a group of cereal crops and animal products obtained only scarce research attention during the period of analysis (see Figure 12).

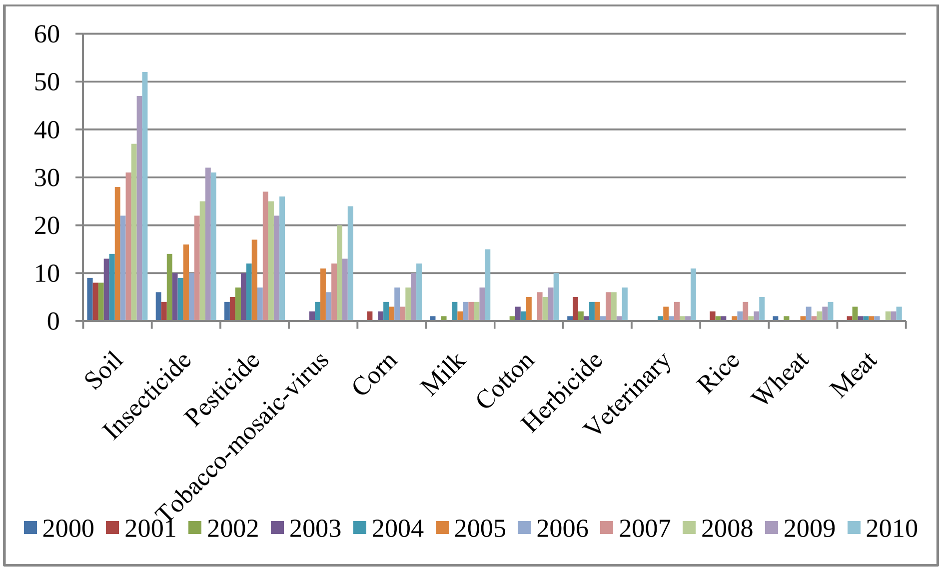


Figure 12: Keywords results of the US Agrifood Nanotechnology Sector in Period 2000-2010

The three main terms found in the period of analysis; soil, insecticide, and pesticide nanotechnology research are directly related with sustainability issues. As I mentioned before, the research that utilize the keyword “soil” in the publication is mainly oriented to two aspects, toxicological studies of nanoparticles in soils and soil remediation. This last one is also linked with the other two more popular terms insecticide and pesticide, both commonly used in crop production that remain in the soil even after harvest producing contamination of soil, water, and food. So then, the focus of research in these aspects contribute two fulfill the four dimension definition of Sustainability goals developed by the US National Research Council Committee on twenty-first agriculture system (2010). In figure 13it is presented the dimensions and indicators achieved by nanotechnology research in regards to soil. This research achieves the four dimensional sustainable goals with direct attention to seven of a total of 26 sustainable indicators. The two dimensional goals best addressed by soil research are the number two "Enhance Environmental Quality and the Resource Base" and four "Enhance the Quality of life for farmers". The benefits obtained from the first one are achieved through the improvement of soil quality by reducing soil contaminants that affect negatively the crop and animal production. With respect to sustainable indicators achieved in the dimension goal 4, the benefits are obtained from the availability of better quality and clean soils, which can contribute to increase crop productivity.

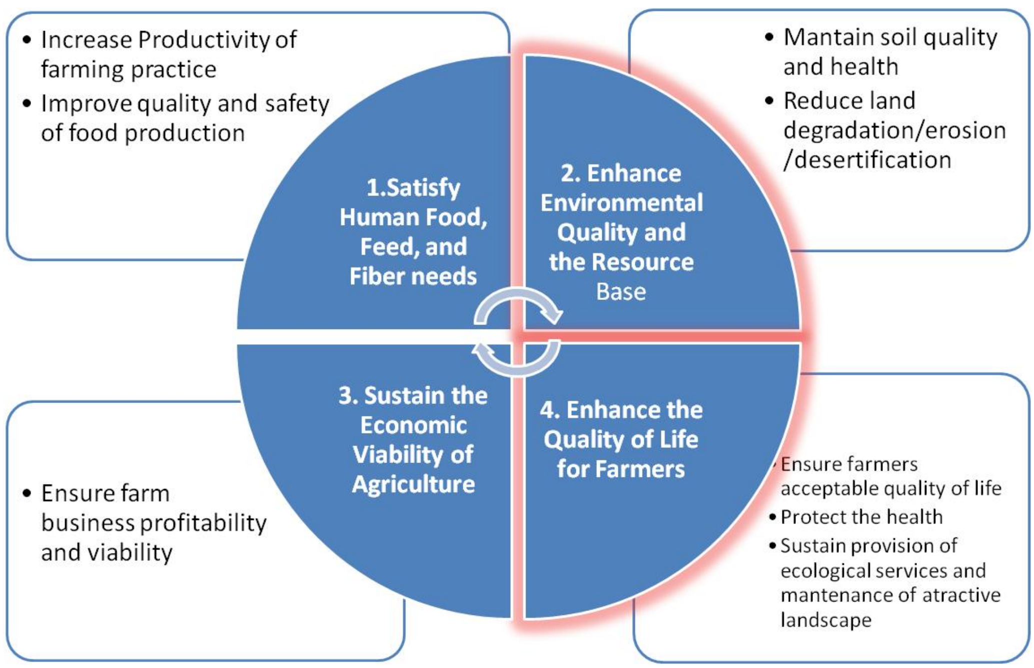


Figure 13: Four Dimension Sustainability Goals with relation to Nanotechnology Research in Soil

In the case of research that are considered as keywords as “insecticide” and “pesticide”, those keywords also contribute to the four dimension sustainable goals. The benefits are not only constrained to farmers and rural population, but also they are extended to food industry’ workers and the society in general, because the research that consider agrochemicals in nanotechnology is also oriented to food processing, in aspect of food toxicity and contamination with agrochemicals as pesticides. Pimentel (2009) calculated as in 10 billion dollar the annual costs in environmental and societal damages produced by the use of pesticides. This negative impact can be minimized with the utilization of nanosensors that have the capacity to detect the presence of agrochemicals in food system contributing to achieve the sustainable goal number four.

The nanotechnology research that study agrochemicals in agrifood sector achieves the four sustainable goals and 12 of the 26 indicators (see Figure 14). Additionally to the two main dimensions of the soil research, this research adds the dimension one: “Satisfy Human Food, Feed, and Fiber Needs” because touch the indicators related to food safety issues.

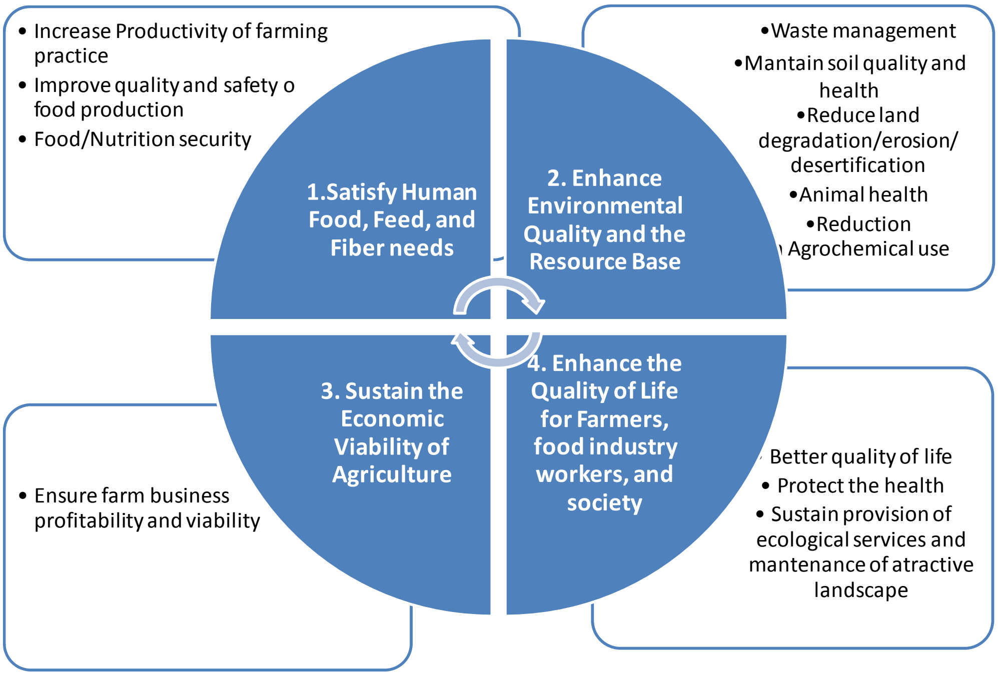


Figure 14: Four Dimension Sustainability Goals with relation to Nanotechnology Research in Pesticide and Insecticide

4.3 The US Agrifood Nanotechnology by Research Area

The Inventory conducted by the Project on Emerging Nanotechnologies of the Woodrow Wilson International Center in 2006 was the first attempt to document the public funded nanotechnology projects in the US agrifood sector. The inventory found 146 government-funded research projects in agrifood nanotechnology(Kuzma 2005). They were classified in 8 research topics. Since 2005 not much change has occurred with respect to the generation of new research topics. Nevertheless, this classification was revised and adjusted with two minor modifications in this research, such as the animal production topic was merged together with the veterinary topic, and the concept of nano-biotechnology was added to the plant production topic, in order to make a clear distinction between nanotechnology research in plant and animal science.

The bibliometric analysis of the US agrifood nanotechnology research in the last ten years shows an important increase in the number of publications in almost all the research topics (see Figure 15). Three research topics illustrate the highest number of publications, with Environmental processing in the first place (50 articles) which represents22% of total US nano-agrifood publications in 2010. The papers classified in this topic use the nanotechnology for studying environmental phenomena, removing contaminants in the environment, or remediating and reducing waste, as well as studies of nanomaterials behavior in the environment. In second level of importance are those articles classified in the topic Bioprocessing for food (40 articles in 2010), which include articles that research the nanotechnology application for better food processing and quality. This topic has shown a fast growing from 3% in 2001 up to 17% in 2010 of the total publications.

Biosensors are in third place of relevance (38 articles in 2010); this research topic has been important since early stages of agrifood nanotechnology development, which represented 15% of the total US agri-nano in 2000, increasing its importance with respect to the other topics up to 25% in 2004 and 2006. They are studies in nanotechnology based on sensors upon biological processes or biological molecules, or for detection of biological molecules, processes, or organisms. Biosensor research is close linked with the other two previous topics described, because of biosensors have been used to detect and control pollutants in the environment, and as pathogen detection tool in food to improve food safety.

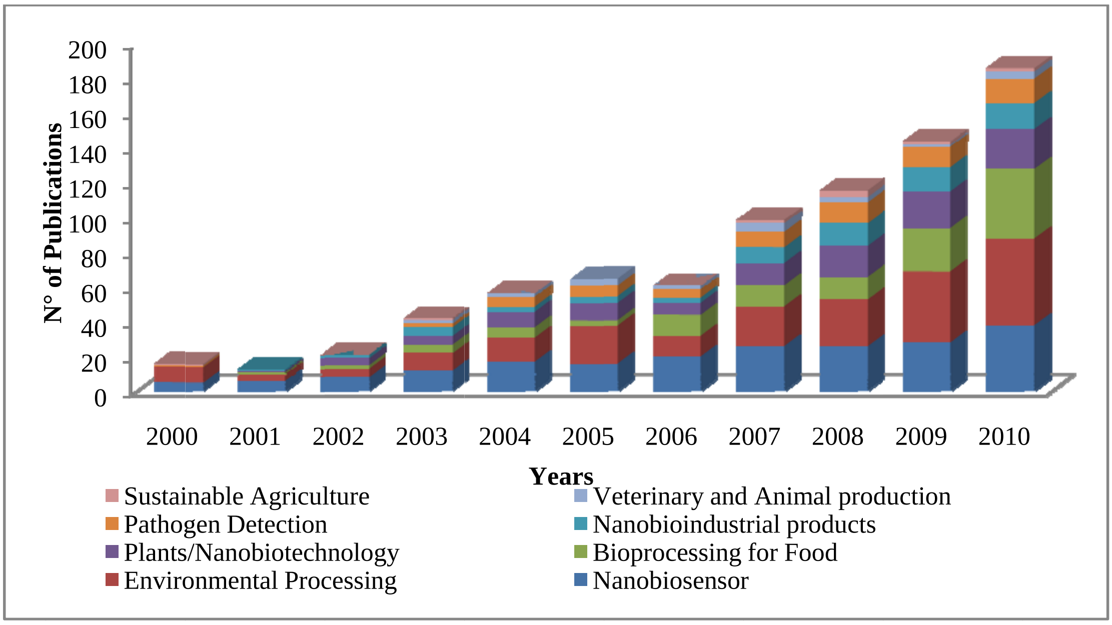


Figure 15: US Agrifood Nanotechnology Research Topics Development in the Period 2000-2010

Sustainable Agriculture and the Veterinary and Animal production were the research topics that have very few publications about, with just a couple of articles yearly.

Considering topics that are directly related to sustainability (Environmental Processing, Biosensors, and Sustainable Agriculture) they were almost all the agrifood nanotechnology research topics in the first two years of the dataset, but since 2002 other topics such as bioprocessing for food and nanobioindustrial products (such as nanocellulose) and nanobiotechnology topics become to be very important during the last years, which increased the trend of growth above the sustainability topics articles (see Figure 16).

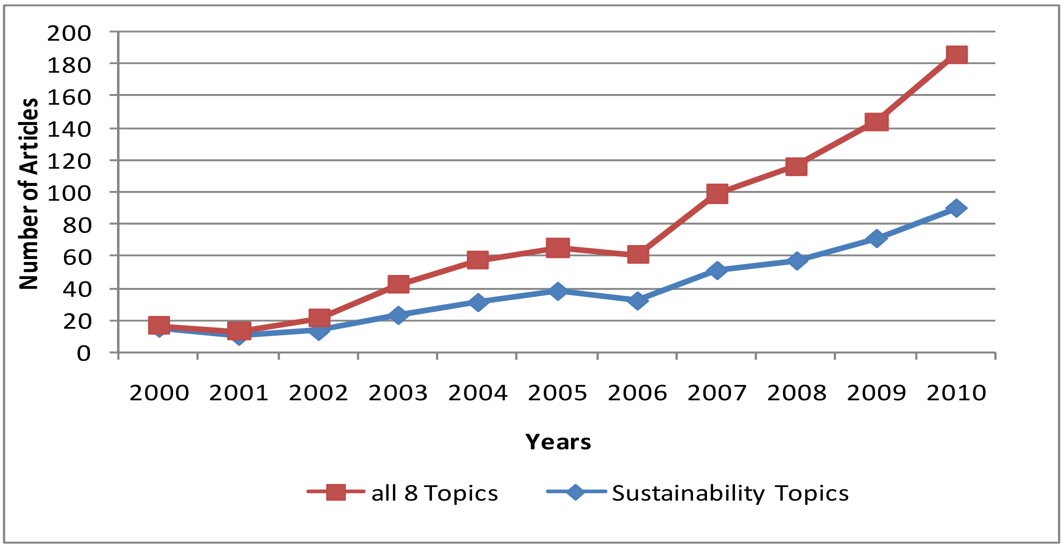


Figure 16: Trend in Nanotechnology Sustainability Research in US Agrifood Sector 2000-2010

In the following section I will illustrate the bibliometric results of the main research topics.

4.3.1 Biosensors:

The Biosensor research in the US agrifood sector has received particular attention in the last decade due to its potential benefits in both agriculture and food processing. Since the first nanotechnology strategy plan developed by the USDA in 2002, biosensor occupied a central research interest because of its potential effectiveness on food pathogen detection, and its rapid response to identify viruses and other pathogens in plants.

The biosensor work is mainly oriented to food safety research. The application of biosensors for rapid detection of contaminants in food is the one that has received more research attention during the last decade, with focus on toxins detection in milk. The biosensor research related to agriculture sector is focused primarily to environmental processing topics, with the presence of a cluster of research in pesticides detection in soils and water (see Figure 17). Biosensors are commonly developed from the association of enzymes and other biological molecules with metallic nano-particles such as, gold-nanoparticles and carbon-nanotubes.

The type of nanoparticles surfaces, their shapes, and physical properties constitute metallic nanoparticles well-suited for enhancing the interaction with biological molecules. This interaction can produce an enzymatic catalysis that have the potential to produce sensitive, selective, and rapid response biosensors for detection of contaminants in food, soils, and groundwater. One of the most studied contaminants has been pesticides applied in crop production that remain in the environment after production processes, these pesticide residues may bring about several problems of contamination of the environment, and they also affect the animal and human health. Therefore, the biosensor research is directly related with the environmental processing category.

Among the main research organizations that are conducting agrifood biosensor research are the US Naval Research Lab (NRL) with 14 publications and the Pacific Northwest National Lab (PNNL). The NRL's mission of studying environmental science, which is conducted in-house research labs, such as the Center for Biomolecular and Engineering, which is oriented towards research and development on rapid detection of foodborne contaminants biosensors. The PNNL from the US Department of Energy conducts research in applied material science and engineering that lead research to monitoring chemicals exposure in the environment and human body. The research mission of these two organizations contribute directly to address issues of sustainability, in particular related to the dimension goal number one: “Satisfy human food, fiber, and its sustainable indicator “improve quality and safety of food output.”

The next groups of research organizations with more publications in agrifood biosensors are universities, for instance the University of California Riverside , Auburn, Penn State University, Purdue University, University of Florida, University of South California, University of Texas, and Michigan State University, with six publications each ones. The research collaboration among universities has been supported by NIFA USDA who has sponsored a multistate research program called “NCDC-201” since 2004. This research group meets once a year to discuss the scientific advancement related to nanotechnology biosensor research, exchange ideas and information, as well as identifies key research and educational activities. The goal of this group is to use nanotechnology to keep the US agriculture and food producers in the forefront on the world nanotechnology development through the application of the benefits from this research to the sector and the society. This project has contributed to generate collaborative research groups in the area of nanotechnology biosensors, this integration of research organizations around different applications from biosensors has made this research topic one of the most relevant in the US agrifood nanotechnology research agenda together with Environmental processing which I describe in the following section.

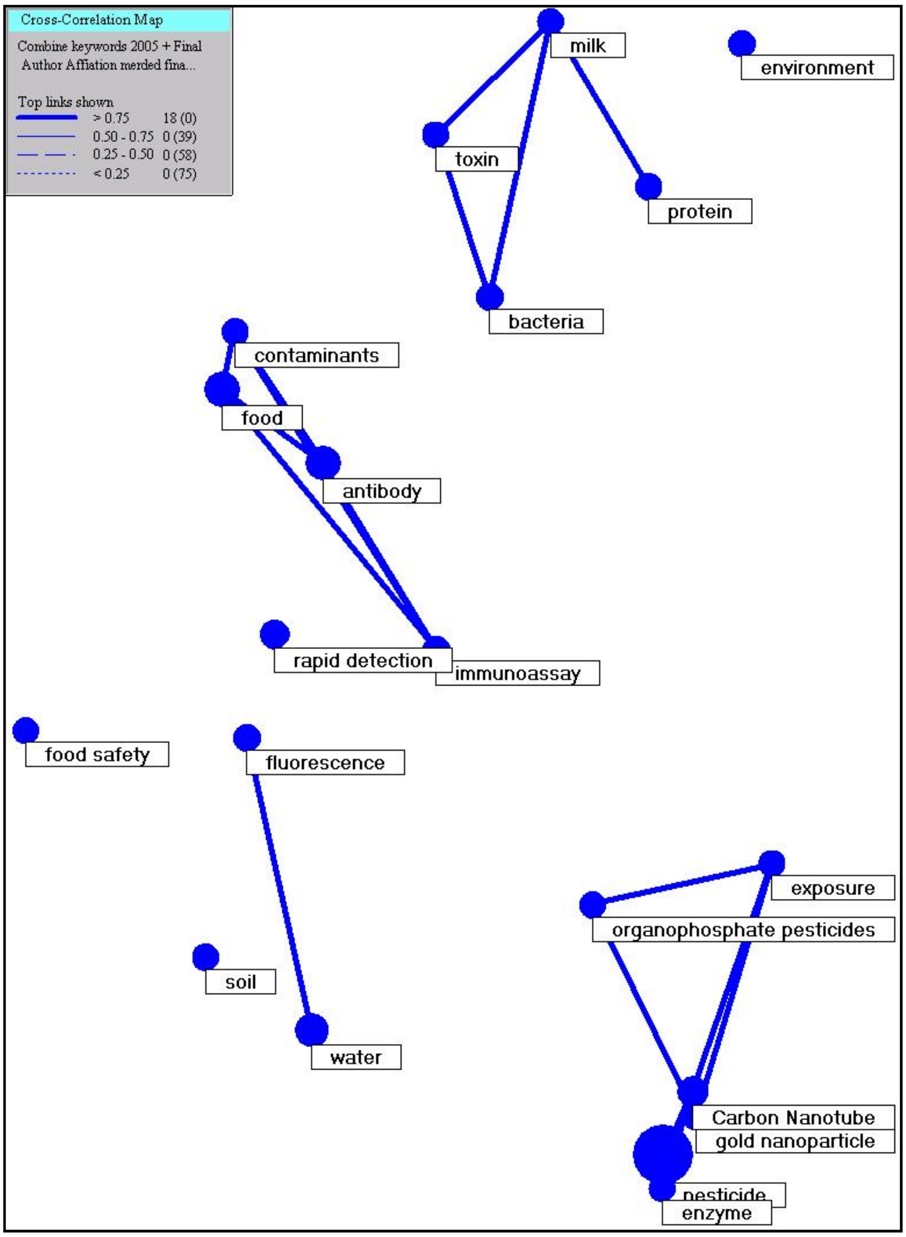


Figure 17: Cross Correlation Map of Biosensors Research in the US Agrifood Sector Period 2000-2010

4.3.2 Environmental Processing

This research topic has been the one that has received most research attention during the last decade in the US agrifood nanotechnology sector. Soil and water were the main research areas conducted mainly by environmental scientists who investigated in two research areas.

The first one is related to analyzing the behavior of nanoparticles and its interaction with the environment, human health, and safety issues from people that could be in contact with nanoparticles (EHS). Environmental risk assessment studies have shown that reactivity, mobility, and adsorption characteristics of nanoparticles have the property to continue their interaction with different ecosystems, even after their utilization in final products, such as the studies related to the interaction of titanium dioxide (TiO2) in aquatic habitat. This nanoparticle is commonly used by the cosmetic, sunscreens, and food coloring industry (Zhang, Sun et al. 2007) and has received NGOs attention that have shown their concerns about and they have conducted campaigns to regulate its use and label the TiO2 product used in cosmetics.

The second relevant research area in the environmental processing is remediation and removing contaminants from soils and water (see Figure 18). For example, several researchers are studying the use of biosensor for pesticide detection and remediation, which are utilized in agriculture production and produce severe environment and human health negative effects in the US (Pimentel 2009). Similar research approach has been utilized to study soil remediation from other contamination sources, such as metals.

The focus of the environmental processing research has been promoted by EPA, which mission is to protect human health and environment, reducing environment risks base on the best scientific information available[8]. EPA developed intramural and competitive grants to research in nanotechnology. Sustainable development is part of the EPA goals, which recognize its role in protecting the environment, making communities and the ecosystems diverse, sustainable and economically productive. EPA integrated the three pillars of sustainability "social-environment-economic" in its mission statement. Hence, the study of the implications of nanomaterials impacts fit into the agency goals with environmental processing research topic as one of the most relevant to them.

EPA also offer competitive grant to other research organizations across the US, as well as other agencies such as USDA. For instance the EPA and USDA has developed solicitation in partnership with USDA NIFA to look at the understanding how nanomaterials transform in ecological matrices, as well as food safety issues related to study the transport of nanopesticides getting into the food[9]

In term of number of research publications in environmental processing topics the main research actors are Department of Earth and Planet Science at the University of California Berkeley who joined with the Lawrence Berkeley Laboratory division on earth science are the main research groups focused in environmental remediation studies (9 articles). Followed by the Ohio State University, Penn State University, and Purdue University (both with 7 articles).

[8] EPA mission statement, last visited October 18, 2012 at http://www.epa.gov/aboutepa/whatwedo.html

[9] Information obtained from one of my research interviews with EPA official.

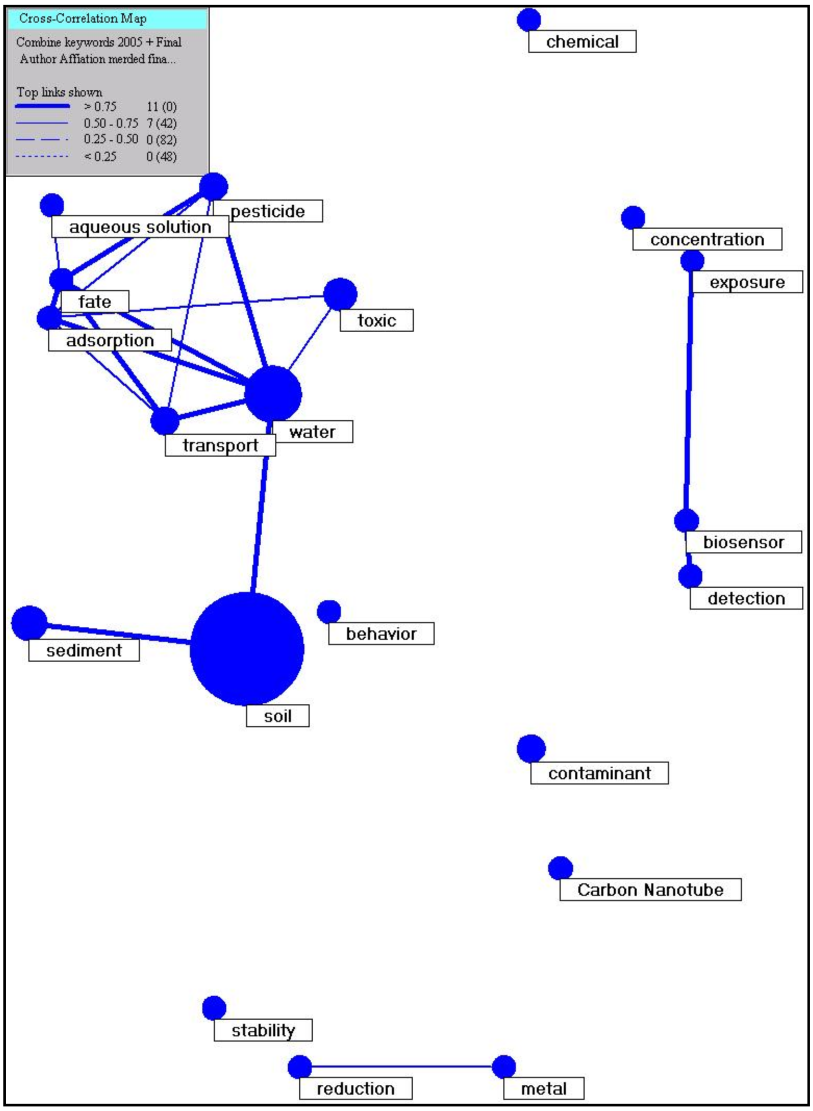


Figure 18: Cross Correlation Map of Environmental Processing Research in the US Agrifood sector Period 2000-2010

4.3.3 Sustainable Agriculture

Nanotechnology research that explicitly used the concept of sustainability agriculture in their research has been very rare during the last decade, only a couple of articles per year that has been published, and most of them with an indirect relationship with the topic, such as the work on soil science to improve soil quality with the study on clays (for example zeolites). Only one article from the sample studied the potential effects of anionic clay as a potential candidate for the development of slow-release nitrate.

The limited attention paid directly to sustainable agriculture in agrifood articles can be explained by the filtering strategy utilized in this research. In which the word sustainability showed-up in just few articles' titles, abstracts, and key-words. Even though there are some articles that describe research that can contribute to sustainability agriculture, they are not explicitly written this word in these articles' sections.

In order to correct this problem, in my methodology I considered three research topics as part of sustainability issues: Environmental Processing, Biosensors, and Sustainable Agriculture.

4.3.4 Pathogen Detection

Pathogen detection research topic could impact positively to improve sustainability. But it is not consider part of the sustainable research agenda because it depends on the type of nanoparticles used as nano-device to test the presence of diseases. For instance, most of the concerns with respect to the use of nanotechnology in agrifood sector come from researchers who see some potential risks when the nano-device considered in the pathogen detection is based on carbon nanotube or metallic nanoparticles (gold, copper, and silver). Although, no scientific evidences have shown negative effects by using these nano-devices, the general claim from social organizations as environmental NGOs and worker unions is that not much effort has been made by the government in researching these potential risks.

Pathogen detection could become sustainable if scientific research confirms the harmless of using engineering nanoparticles or if those ones can be replaced by natural base nanoparticles, such as nano-cellulose or corn starch.

The research conducted in the US respect to pathogen detection is almost exclusively oriented to food safety issues. Bacterial detection of Escherichia coli and listeria-monocytogenes (see Figure 19), which are two major human pathogens, being the responsible of severe problem of infections by eating contaminated food. So then, the main research area is concentrated in the rapid detection of contaminated food with these bacteria in order to reduce the annual costs produced by foodborne infections and intoxications in the US.

The DNA biosensor is the most utilized nanotechnology tool among the researchers who are looking for study cheaper, easier to use, and quick pathogen detection tests.

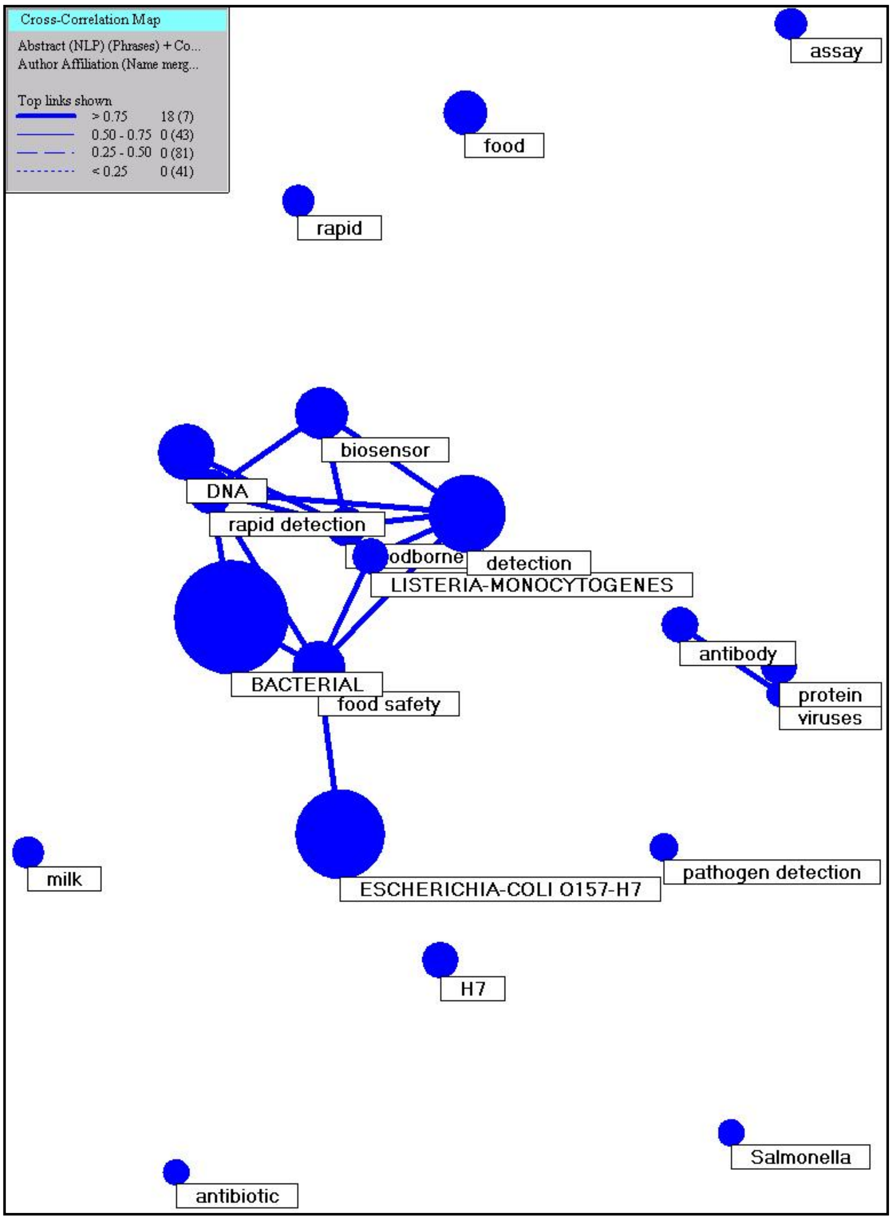


Figure 19: Cross Correlation Map of Pathogen Detection Research in the US Agrifood sector Period 2000-2010

4.3.5 Plant Production and Nanobiotechnology

Nanotechnology research applied to plant production has received some attentions in the US, especially in the second half of the last decade with an average of 19 articles published yearly (2007-2010). From the total of 111 publications in this research area, only 2 publications utilized the concept of nanobiotechnology to define their research as the combination of two fields, biotechnology and nanotechnology. The main research focus in this area is focused on the study of nanoparticles toxicity effects in plant system, rather than to find practical applications of nanotechnology to improve crop productivity. This effect can be observed in Figure 20, where the main cluster of research keyword is the one concentrated in carbon nanotube interaction in cells plant, root system and plant growth in contaminated soils. The bibliometric analysis found just few articles that used nanoparticles such as nano silver to study properties as control fungal plant disease. Even though this type of research seems very small in term of number of publications, it is very relevant in term of sustainability because if new improvements to plant production are achieved thank to nanotechnology, it can impact positively in the sustainable dimension goal 3:"Sustain the economic viability of agriculture and food production."

The main research actors involved in plant nanotechnology research are: the University of Texas (9 publications), the USDA agriculture research service (with 8 publications), and the Department of Plant Science at University of Arizona (with 5 publications).

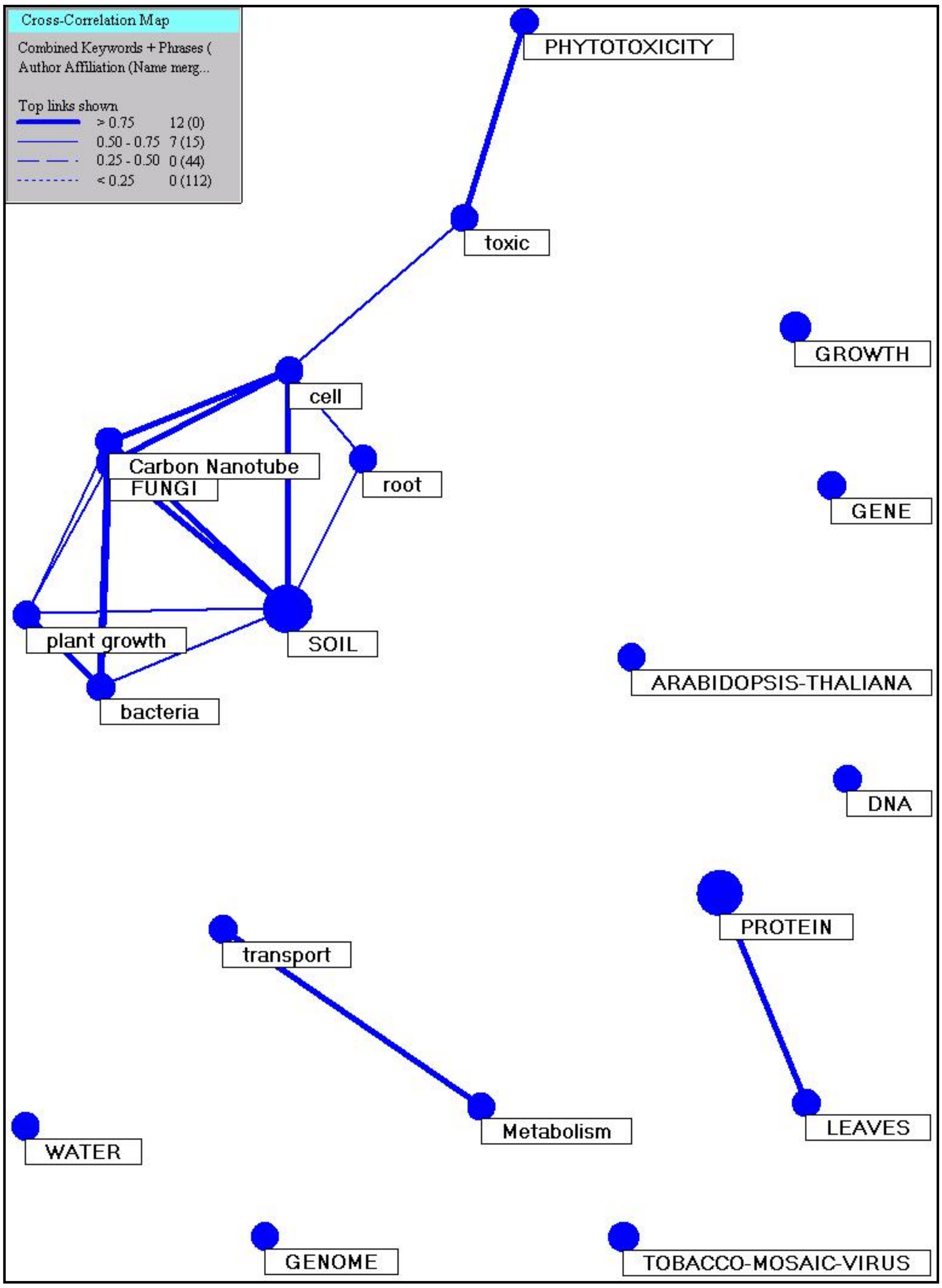


Figure 20: Cross Correlation Map of Plant Production and Nanobiotechnology Research in the US Agrifood Sector Period 2000-2010

4.3.6 Veterinary Medicine and Animal Production

This research topic is one of the less studied with respect to nanotechnology applications, with only a couple of articles published each year since 2005, with emphasis in veterinary medicine for cattle and poultry production. Drug delivery has been one of the areas studied during the last five years. Disease detection is another area that has some interest from scientist who utilizes nanotechnology to identify animal diseases (see Figure 21).

The research on nanotechnology applications in veterinary medicine and animal production has been conducted in some few veterinary schools from universities such as: North Caroline State University and University of Florida.

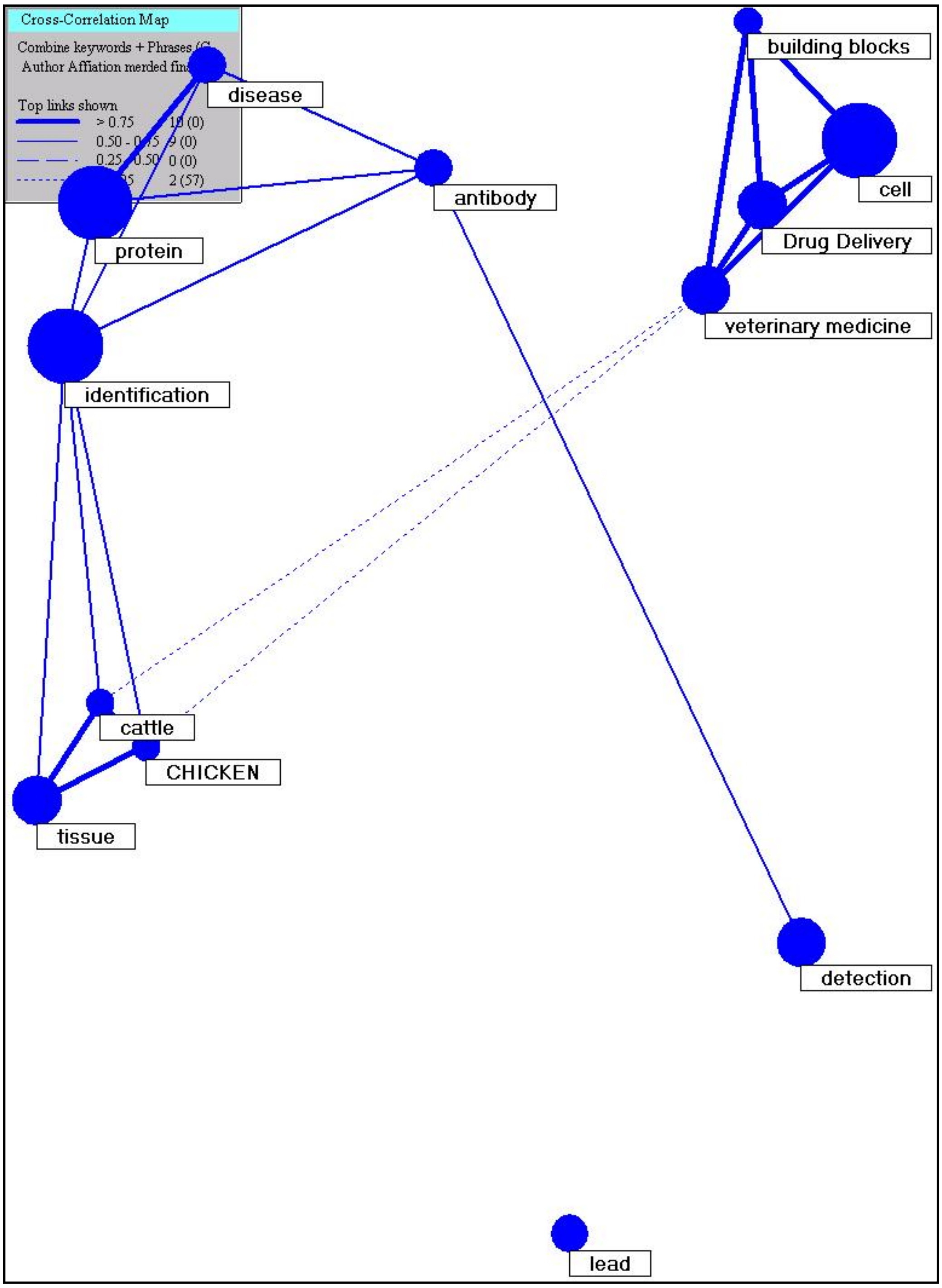


Figure 21: Cross Correlation Map of Veterinary Products Research in the US Agrifood Sector Period 2000-2010

4.3.7 Nano-bioindustrial Products

This research topic considers the development of new industrial products coming from agriculture, as row materials that are transformed in nanotechnology applications have received more relevant research attention since 2007 (see figure 22). This positive shift in publications trend is noticed only one year after the USDA Forest Service started its nanotechnology research funding program. This new program is oriented principally to the development of nanotechnology wood-based materials such as the lignocellulosic materials. The Forest Service nanotechnology research agenda is divided in three areas:

- Characterizing nanoscale structure of wood,
- Studying the structure and characterization and application for forest base nanomaterials or nanocellulose, and
- Using nanotechnology in forestry or forest product, for example wood preservation, looking nanotechnology in forest management.

Hence, if the new wood-base and other natural-base nanoparticles prove to work as new biodegradable nanoparticles, it can be an important contribution to sustainable development. If this happens, then this research topic can achieve the four sustainable goals, because it will contribute to solve an important problem for the human health, with no negative impact in the environment, improving the farmers' quality of life, food industry workers, and the society. Additionally, it has the potential to improve the sustainable dimension 3:"Sustain the economic viability of agriculture and food production." This dimension has been the one less achieved in regards to nanotechnology contribution to sustainability issues. Farmers and wood producers can obtain the direct benefits from the development of new natural-base nanoparticles because they can provide the raw material required to the production of these nanoparticles that could be applied in other industries, for example the USDA Forest Service is conducting a collaborative research with eight universities research centers for using nanocellulose materials in the aircraft industry.

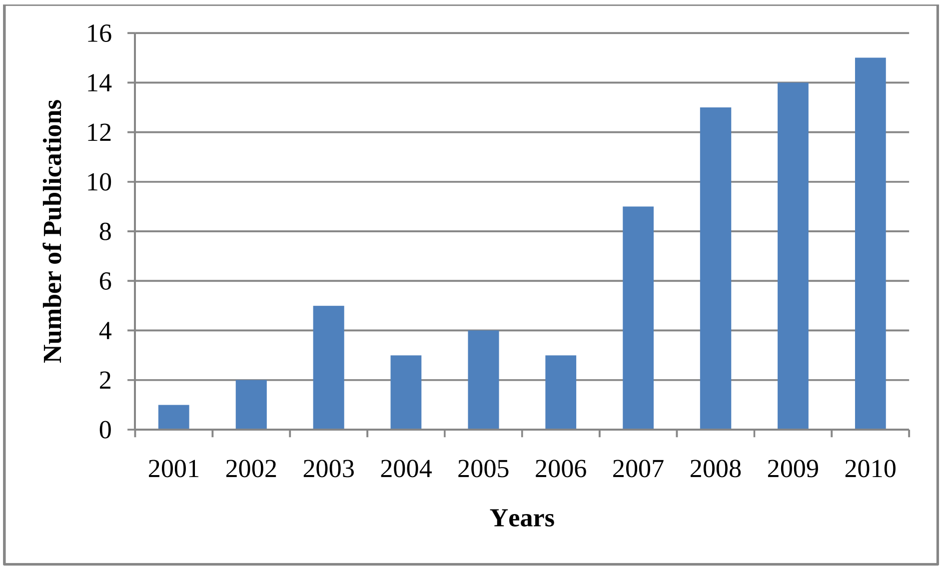


Figure 22: Number of Publications in Nano-bioindustrial Products Period 2000-2010

The concentration of nanobioindustrial products on wood sub-products is observed in the Figure 23, which shows a cluster on nanofibers and polymers obtained from wood cellulose and the cotton obtained from agriculture crops. A second small cluster is developed from plastic polymers and textiles got from bio-based nano-materials.

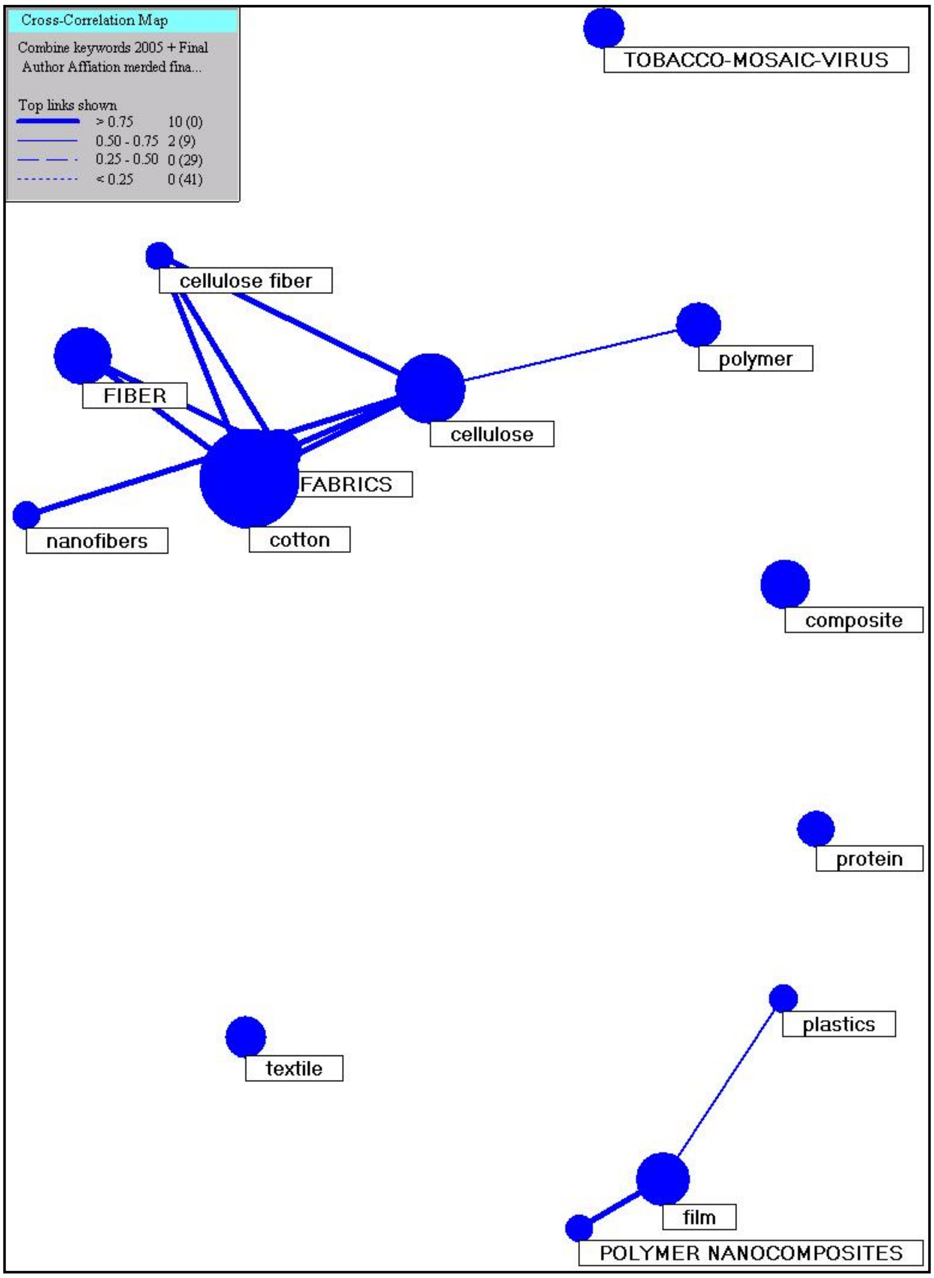


Figure 23: Cross Correlation Map of Nanobioindustrial Research in the US Agrifood Sector Period 2000-2010

The principal research groups are located in intramural research at USDA ARS Environmental Management & by Products Utilization Lab. Beltsville, Cotton Fiber

Bioscience Research Unit in New Orleans, and from the Forest Service Forest Product Laboratory in Madison Wisconsin. Nanobioindustrial products for textile research are mainly located in the Department of Fiber Science & Apparel Design at Cornell University and the Department of Bioproducts & Biosystems Engineering (BBE) at University of Minnesota, which are working in cotton biopolymers nanocomposites. The BBE has the development and applications of renewable resources and sustainable technologies as part of its main institution goals.

4.4 US Agrifood Environmental, Health and Safety (EHS) Research

The research agenda oriented to EHS issues in the agrifood sector has also becoming to receive more attention in term of number of publications dedicated to study the toxicological effects of nanoparticles in the environment and human health. Toxicity, risk, and safety are three keywords commonly associated with EHS research. In the bibliometric analysis they showed an important increase in terms of publications, specially the second half of the last decade (see Figure 24). The first years of the 2000's decade only a couple of scientific articles included some of these keywords. Since 2007 a higher enlarge number of publications were observed, in particular respected to safety studies. These results were compared with a previous study conducted by Youtie, Porter et al. (2011) which utilized similar methodology to select works in EHS publications, they found about 2% of the world nano-publications were oriented to EHS in 2004, this trend slightly increased up to 3% in 2007. In this research the authors recognized that the agricultural science (which included food science) and ecological science were two areas underrepresented with respect to the number of total publications, in spite of the potential implications for nanotechnology research. Comparing my results that utilized the similar methodology and database, but I only considered the US agrifood nanotechnology in the same years, which obtained 1.4% and 10.3% respectively. These results evidence the relevance that EHS research has occupied in the US agrifood nanotechnology research agenda since the second half of the last century, conducted mainly by EPA, NSF, and USDA agencies that have worked together to develop intramural and competitive grants to investigate in this research area.

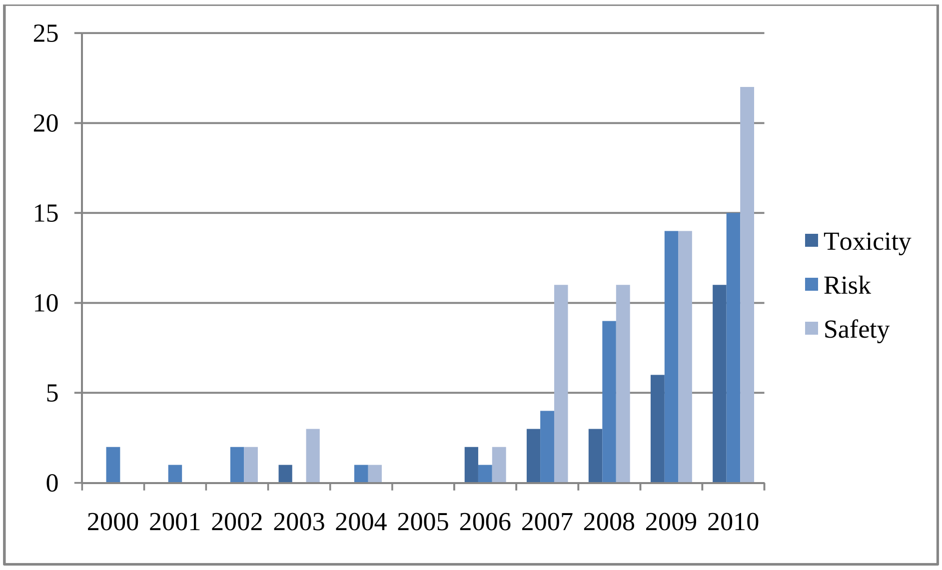


Figure 24: Publications in Agrifood Nanotechnology Related to EHS Research Period 2000-2010

Among the most important research institutions that were conducting agrifood nanotechnology research related to toxicity were, Auburn University (5 publications) followed by Duke University and U South Carolina (each with 4 publications). Two Federal agencies the EPA and the USDA ARS were among the top ten organizations that most considered topics related to toxicity the research they published. In relation to research that used the keyword “risk” in their scientific publications were University of Minnesota, Cornell, and Duke University. Finally, the publications that used the word safety were found in Cornell, University of Texas, and South Carolina, also relevant to mention two USDA ARS publications that used the concept of food safety in two articles.

The majority of research actors are leading research in collaboration with scientists from other research centers. Nevertheless, some exception to research collaboration is observed in universities such as MIT, Cornell, and Ohio State University, among others that have worked individually separated from the big cluster of researchers from universities and intramural research organizations as the USDA ARS (see Figure 25).

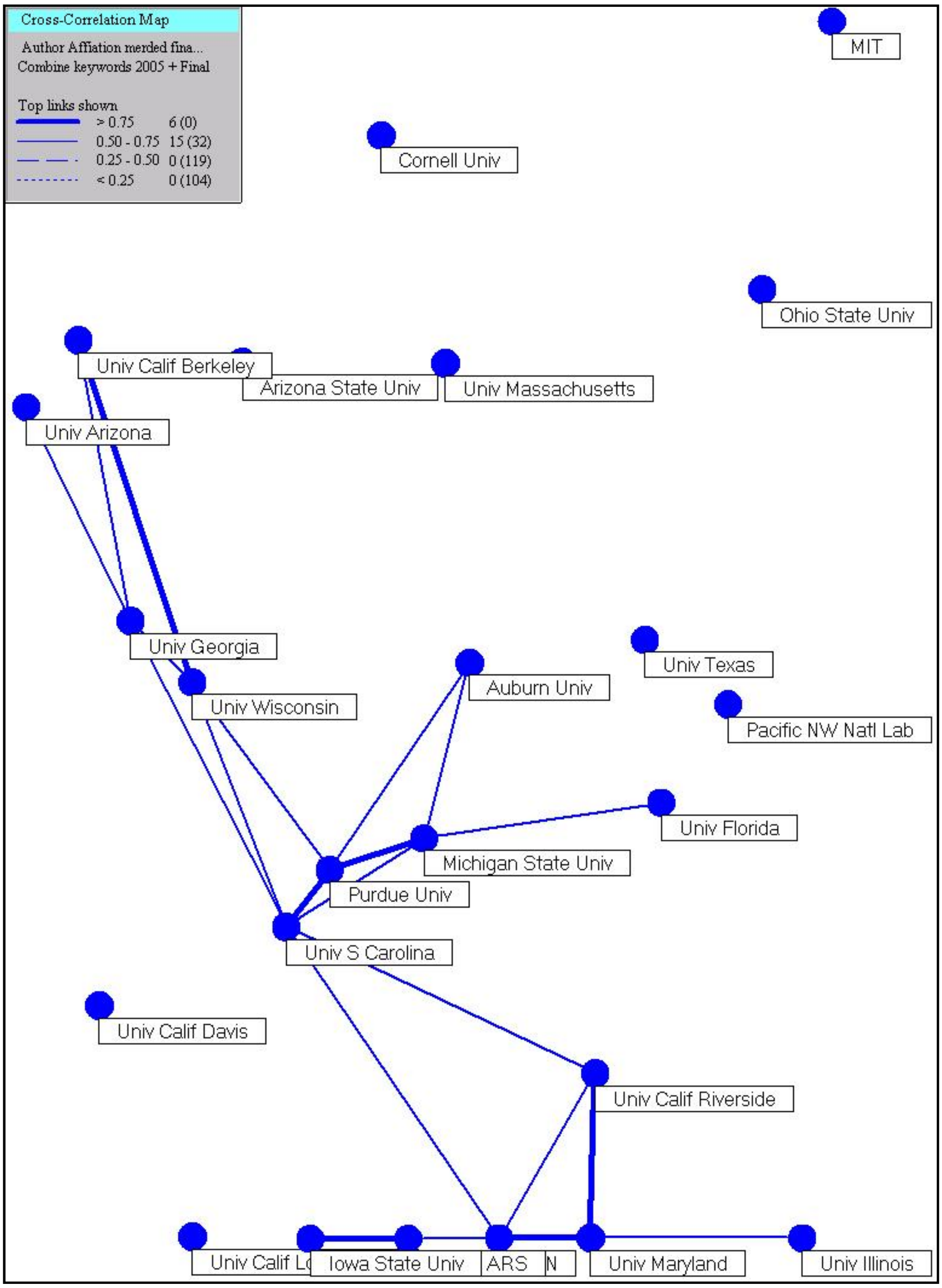


Figure 25: Cross Correlation Map of EHS Research Collaboration in the US Agrifood Sector Period 2000-2010

4.5 Conclusions

The bibliometric analysis of the last ten years of agrifood nanotechnology research in the US showed the effect of a constant public support to research in this sector, with a result of an increasing number of publications yearly. An important participation of researchers from research centers at universities, national laboratories, and intramural research groups in USDA and EPA. These federal agencies together with the NSF have been the main sources of research funding in agrifood nanotechnology, that promote the interaction among the US researchers. They play an active role in the research agenda, participating in annual meetings where they present their research advancement and use the opportunity to make known new areas of research that federal agency managers' should pay more attention to invest in. This increase in research activities represented by number of publications situated the US as the world leader in this research area. This leading position reached its pick in 2005 with the 30% of the world publications. Nevertheless, this lead position with respect to the number of research publications has become to diminish during the second half of the last decade, with the climb of China as the world leader in nanotechnology agrifood research, shrinking the participation of the US to around 21% of global publications.

With regards to the research topics that received more research attention in the US agrifood system are food processing and environmental processing nanotechnology. Hence I can conclude based on the bibliometric analysis that more research attention has been oriented to environmental processing, development of biosensors, and food safety issues. This research found very few research articles about nanotechnology application in agriculture, which has been the traditional focus of the US agrifood research agenda with the main emphasis in increasing farm productivity. This finding is not the same one which I expected because in most of the literature of nanotechnology in agriculture and food production, the first one appeared to be as relevant as food applications. Even more, in the strategy plans conducted by USDA together with the US scientific community agriculture applications are always among the top priorities of research.

This research orientation is highly influenced by research funding available in federal agencies programs that focus their competitive grants to finance projects in these areas. For instance, the USDA NIFA has promoted food safety topics of research; meanwhile EPA has prioritized environmental processing as one of its areas of research interest. My analysis revealed an increasing relevance of EHS studies in nanotechnology research, especially since 2007. This type of research that search for understanding the behavior of nanoparticles in the environment, human body, and safety issues are implicitly on the same direction to achieve a sustainable development, because their research focus are not only oriented to obtain new products to the market to produce economic wealth from this new technology, but it also studies the properties that can enhance a more environmental and human friendly technology.

In the following chapter I will study the factors that affected the shifting on research orientations of the agrifood nanotechnology, to reach my dissertation objectives I utilized a qualitative analysis of semi-structured interviews with key actors of the agrifood sector, in order to evaluate if the formations of advocacy coalitions have influenced the research agenda.

CHAPTER 5.

ACTORS AND NETWORKS – THE INFLUENCE OF ADVOCACY COALITION GROUPS

5.1 Introduction

This Chapter is focused on the analysis of the actors and networks involved in the US nanotechnology agrifood sector. I used the Advocacy Coalition Framework to analyze the presence of coalitions groups which members work together to try to influence on the decision respected to the orientation of the US nanotechnology research agenda. Two criteria were considered to establish the presence of coalitions. The sharing of a common set of beliefs among the coalition members with respect to the use of nanotechnology in the agrifood sector, as well as the evidence of nontrivial set of coordination among the coalition members, such as participation in meetings, coauthorship in publications, reports, and presentations, sign of public comments, among others. The ACF framework from policy process helped me to recognize two advocacy coalitions, the pro-nano and the pro nano-regulation. The pro-nano coalition was first observed in the USDA workshop to develop the agrifood nanotechnology research roadmap in October 2002. It is mainly integrated by researchers, federal agency managers, and industry representatives, who have been active participants in the research agenda in terms of influencing federal agencies with respect to suggest research areas and topics that should be prioritized. The rival coalition is the pro nano-regulation, which was formed later in 2005. The most active members in this coalition are policy analyst from environmental NGOs and worker union representatives. Additionally to the two coalitions, I found out two subgroups inside the pro-nano coalition, which I named the "pro-EHS research", they started to influence the agrifood nanotechnology research agenda to invest more public funding in study the environmental, health, and safety effects of using nanotechnology in 2006. This subgroup is formed by agency officials in charge of EHS funding programs and environmental and social science researchers. The other subgroup is the "bio-base nanoparticles" subgroups, which is the most recent formed, they were born in the USDA Forest Service being the grantees of research funding, who recognize a sustainable way to produce nanoparticles that can replace the engineered nanoparticles, they have been source of big concerns respected to potential risks associated to them. These new development of natural base biodegradable nanoparticles are mainly taking from cereal crops and wood-cellulose.

Each of the two coalitions and two subgroups members shares a similar set of beliefs and arguments that encourage them to adopt collective actions in order to their ideas and points of view gain attention from policy makers. The formation of advocacy groups in relation to nanotechnology research has brought about a public debate in regards to the kind of research areas that should be promoted by public research funding in the US.

The bibliometric analysis presented in the previous chapter was mainly focus on obtaining and reviewing data about researchers who published articles related to agrifood nanotechnology. This methodology is insufficient to constitute a deeper analysis in regards to advocacy coalition presences. Moreover, this type of bibliometric studies just take into account partial information from each article analyzed, such as name of authors, affiliation, year of publication, title, abstracts, and keywords, among others. Considering that other relevant actors not publish regularly in scientific journals, they are underrepresented in these databases.

To achieve my thesis goals I included a further step of analysis of other data sources such as interviews with key actors not only scientist but also policy makers and social actors as NGO's and worker unions' representatives were incorporated. Additionally, I reviewed press releases and other internet reports that commonly are used by these types of actors that interact in the policy debate about nanotechnology in the US.

Policy makers and members of nongovernment organizations that participate in the nanotechnology debate use different ways to reach the public audiences, such as media campaigns to spread out their arguments and opinions respect to nanotechnology. Therefore, I conducted twenty-four semi-structured interviews, lasting an hour on average, with staff members of federal regulatory agencies, staff members or individuals otherwise associated with nongovernmental organizations (NGOs), worker Unions and International Organizations, and academic or governmental members of the US nanotechnology research community. The transcription of these interviews were analyzed utilizing Nvivo software that helped me to organize the topics and arguments presented by each actors in order to find the presence of advocacy groups and their members. The analysis of their beliefs, arguments, collaborations, actions, and resources used to defend their position related to the nanotechnology research in the US agrifood sector are the qualitative approach used in this research to determine the presence of advocacy groups and the members who are part of them. These results are presented and discuses in the following sections of this chapter.

5.2 Evidence of Advocacy Coalitions in the US Nanotechnology Agrifood Sector.

The Public research agenda oriented to support investigations in nanoscience and nanotechnology in the US has received public support since the establishment of the national nanotechnology initiative in 2000. The context by which the research goals were set by this interagency initiative and its members (mainly USDA, EPA, and FDA in agrifood sector) was described in Chapter 3 of this thesis. The development of research roadmaps by funding federal agencies have been almost exclusively developed with the opinions and ideas coming from Land Grand universities researchers, members of other public research organizations, and in few opportunities the initiative also considered the industry’s ideas and expectations about nanotechnology contributions to their sector. But the NNI has omitted the participation of several other important actors of this sectoral system, such as farmers, consumers, social organizations and potential end-users of new nanotechnology applications. For instance, the first USDA agrifood nanotechnology roadmap workshop participation list included 67 university researchers, 35 federal agency members, and 5 agrifood industry representatives.

The first competitive grants program for nanotechnology research in the USDA called the “Nanoscale Science and Engineering for Agriculture and Food Systems” was designed and carried out thanks to the ideas and visions in regards to potential contributions of nanotechnology in the agrifood sector discussed in the USDA workshop in 2002, with an influential participation of universities researchers. This influence from researchers is described in my interview with one of them who participated in the organization of that workshop that mentioned the following:

"They were probably in very few projects, or involved in an early stage with nano. They were people that came from universities across the nation, universities with agricultural college and land grant universities. They came to discuss develop a sense of the future if they chose to do nanotechnology research."

This group of researchers has become grantees from USDA funding programs in nanotechnology. They have advocated since then for more research funding oriented to nanotechnology research in the agrifood sector. Meanwhile, Industry has played a more silent role respect to be involved in the research agenda discussion, this position is pointed out by one of my interviewee, who refers about industry participation in the workshop, in the following paragraph:

"Yes, some of the food industry, from the grocery manufacturing association to the IFT (Institute for Food Technologists). But it is hard to get companies to do much because they are so sensitive to the fact that they are working in nanotechnology products and then the public can develop concerns and produce problems for them, so they are very hidden about what they disclose, they obviously are researching nanotechnology but they keeping quiet about it"

The early involvement of researchers in the policy process of the US nanotechnology research agenda has contributed to the formation of the first advocacy coalition which members are mainly researchers and some promoters inside of federal agencies such as USDA. This pro-nanotechnology group advocate for more federal funding available for nanotechnology research in the agrifood sector. They emphasized a set of potential benefits from nanotechnology that can originate a revolution in the manner food is produced. Their arguments have been incorporated in several reports and presentations, some of these are mentioned in the following Table.

Table 5: Pro-nano advocacy group Line of Argumentation

Report: Exploring new opportunities for extension[10]. June 2002	*"Recent research advances in information technology, biotechnology, and **nanotechnology** have put agriculture at the threshold of an exciting frontier of opportunities to advance economic growth, sustainability, and the building of human capabilities"*
USDA National Nanotechnology Road map 2003.	*"**Nanotechnology** is an enabling technology that has the potential to revolutionize agriculture and food systems."*
CSREES Administrator's Report to the Partnership[11] November 2007	*"The tremendous potential of **nanoscale science** and **nanotechnology** to revolutionize agricultural and food systems has been clearly demonstrated through various programs supported by CSREES, as well as the R&D initiatives of the private sector and academia."*

In the following section I present the results of the interviews with members of the agrifood sector that participate in an advocacy coalition focusing their efforts to allocate more public funding for nanotechnology research in the agrifood sector. I describe their beliefs respect to nanotechnology, their resources utilized to influence the policy process, and type of actions that confirm non-trivial coordination of activities.

[10] http://www.nifa.usda.gov/about/white_papers/pdfs/exploring.pdf
[11] http://www.nifa.usda.gov/about/white_papers/pdfs/exploring.pdf

5.3 "Pro-nano" Advocacy Coalition A

This coalition is formed mainly by researchers at universities and program managers in federal agencies that support public funding to nanotechnology research in the agrifood sector such as USDA NIFA. The first step to organize this coalition was the USDA workshop called "nanoscale science and engineering for agriculture and food system" in October 2002, during this workshop was developed the nanotechnology research roadmap and further the public call for research in the area.

The Institute of Food Technologists (IFT) has become a new relevant partner of this advocacy coalition. This society for food science and technology is a non-for-profit international scientific and educational society with 22,000 members working in food science, food technology, and related professions in industry, academia, and government, IFT created the food nanoscience working group in 2006, which is formed by around 50 members affiliated with the food industry, academia and the U.S. Department of Agriculture. This working group serves as a "leader and catalyst for the community of researchers exploring the impact of nanoscience and nanotechnology on food[12]."

5.3.1 Beliefs of Advocacy group Pro-nano

This group has a similar set of beliefs in relation to the other members of the pro-nano coalition, especially about the necessity to increase research funding in nanotechnology for food to accelerate the potential benefits to impact positively the food

[12]IFT Comment on Consideration of FDA-Regulated Products That May Contain Nanoscale Materials; Public Meeting Docket No. FDA-2008-N-0416, last visited on October 20 2012 at http://www.ift.org/public-policy-and-regulations/advocacy/ift-comments/2008/fda-on-nanotechnology.aspx?page=viewall

industry. For instance, one of my interviewee commented “USDA has not sufficient funding compared with other agencies. I think it is not enough, they should increase it.”This complementary vision of unfunded program is also shared by IFT who advocate for increase funding to increase research funding support, this point of view is presented in IFT’s goals showed in the following table:

Table 6: IFT’s Food Nanoscience Working Group Strategic Plan

“The goal of the working group is to facilitate the acquisition, generation, and communication of technical and safety developments of nanoscale materials for food applications in order to advance the pursuit of scientific endeavors, encourage collaboration among organizations with interest in food nanoscience, and ***influence regulatory agencies, consumers, and the general public’s decision making regarding nanoscience and food.***

The group’s objectives are to position IFT as a leader in the community of researchers exploring the nanoscale science of food and provide a forum for stakeholder engagement; to leverage partnerships with leading nanoscience research and policy institutions to encourage collaboration and exchange of information, and to ***advocate for increased funding for nanoscale science of food.”***[13]

[13]I FT 2007 Annual Meeting & Food Expo Review: Food Nanoscience Conference, last visited on October 18, 2012 at http://www.ift.org/Knowledge-Center/Read-IFT-Publications/Science-Reports/Conference-Papers/~/media/Knowledge%20Center/Science%20Reports/Conference%20Papers/0907nanoscience.pdf

The core beliefs shared by members of this coalition are focused on the advancement of scientific research and its contribution toward the human social and economic development. In the case of nanotechnology research in the agrifood sector can improve the competitiveness of the US industry. So then, it is required to increase the public funding invested in basic and applied nanotechnology research oriented to agrifood sector, because more funding for research can increase innovation, generate new products and provides the sector higher market competitiveness locally and internationally. IFT recognized specific areas of food production that could obtain benefits from nanotechnology research such as:

- Safer and more nutritious food products with better quality and stability
- Improved processing and packaging systems that enhance food safety, quality and shelf-life, and reduce environmental impact
- Better ingredients and nutrient delivery systems that promote consumer health and wellness
- Reduced energy use
- Other benefits, such as reduction of food losses

Similar orientation of benefits toward increase productivity is observed from my interviews, a researcher who has worked in the establishment of the US agrifood nanotechnology research agenda who gave a similar argument as previous agr-biotechnology promoters that justify public funding investment due to these kinds of technologies can improve agricultural productivity, which is represented in the following excerpt:

Table 7: Arguments Coalition A to Support Their Research Area.

Interviewer: What is the slogan for nanotechnology promoters? **Interviewee:** Well, nanotechnology can increases productivity, putting fertilizer right where the plant seed are, so you will not spread too much fertilization. You can also put a number of sensors in the field for irrigation only when it is needed. In animals you can track animal from farm to your plate, you can change the animal production conditions too, reduce the methane emissions from manure.

Members of the Pro-nano coalition are aware about potential risks associated with nanotechnology. They believe that these potential risks must be studied to reduce public concerns respect to this new technology. But they advocate for avoiding the reduction of the scarce research funding has a consequence that some non-governmental organizations have risen these apprehensions respected this emerging technology. Moreover, they think potential risks should not constrain the development of the sector, because those risks can be managed as in previous experiences with the utilization of new technologies that have been very beneficial to the humanity but at first they could cause some problems that need to be solved before the technology reach the market. They compare the nanotechnology with the introduction of x-rays technology in health treatments and airline security. It has been a very useful diagnosis tool but in the first stages of its implementation, people did not take sufficient safeguards to reduce risk of exposure to radiation. Nowadays, as a result of the intervention taken by the actors involved, and after safety preventions have been taken, this technology has been proved to be very beneficial.

The benefits/risk dichotomy is presented in the debate of using nanotechnology in the agrifood sector. There are some members of the coalition that have differences in regards to put more attention in one of these two sides of the coin. On one side, several researchers that aim for more federal funding into nanotechnology applied research to produce new products are focusing more in standing out the benefits rather than risks. This optimistic view of science is reflected in the following comment of a researcher of the coalition A:

"The right message is to analyze what kinds of nanoparticles have negative and positive effects. Because if you look all the websites, they never talk about environmental effects. Most people talk of toxicity, but never talk about the benefits. The benefitsare not only for the industry. People have these big concerns because they do not know about nanotechnology but they see the news -- "carbon nanotubes are bad, this nanoparticle is bad, etc."-- so you can say if I put a product with a nano particle in the market, nobody will buy it."

On the other side, some members of this coalition seek to focus more in the understanding of nanotechnology rather than applications. These members formed a subgroup coalition Pro-EHS research.

5.3.2 Advocacy Pro-EHS Research Subgroup

This pro-nano subgroup was formed after the first concerns showed up from environmental NGOs in 2006, who claimed for a lack of transparency and information with respect to the agrifood nanotechnology research agenda and its potential risks associated to the use of engineered nanomaterials, such as carbon nanotube, gold, silver, and titanium dioxide nanoparticles in agriculture and food production.

Members of this group are federal agency managers that are in charge of the environment, health, and safety research supported by their organizations, as well as several professional societies, such as the environmental society, the society of toxicology, and the risk assessment society. Initially the research in nanotechnology promoted by Federal agencies such as EPA and NSF was oriented to green processing, and then they started a transition into looking the potential impact of those nanomaterial when they reach the environment, what those transformation mean in terms of exposure for both biological and the ecosystem (EHS research).

This shift was explained in one of my interviews with an environmental engineer working at EPA:

“I think this was a global shift as well. We have these nanomaterial going to the environment, what may be the potential issues? Would it be exposure to the public? Would they would be exposed but without any risk? So, as our mission is to protect human health and environment, we needed to focus on that.”

They agree with considering nanotechnology as a powerful tool for the agrifood sector, but at the same time, they recognize many unknown effects of the technology, these require more research on studying the interaction of nanoparticles in the environment and human health in order to search for some potential risks. These risks need to be reduced as much as possible in order to receive higher benefits with low risks in using this technology. This subgroup’s members are principally environmental and social science researchers and some policy makers at EPA and NSF that encourage the government to provide with more research funding oriented to environmental, health, and safety (EHS) issues, these ideas are articulated in the following piece of interview where researchers and a federal agency manager explain the concern they have in mind:

Table 8: Arguments Subgroup Pro-EHS Research

Interviewer: How do you see your research respect to EHS issues?
Researcher 1:*I think this is very important, we need to be very transparent in conducting research in nanotechnology because the public is being expose to something they don't fully understand, they do not understand the risk involves, so we need to invest resources to show what part of nanotechnology is safe and what part is significant risky, we would like to see funding for toxicology work to be increased.*
Researcher 2: *All nanomaterials behave differently depending on the composition. Hence there are needs to be a lot of research done on the particles and how they behave.*
Interviewer: Do you think that it is enough funding for EHS in your organization?
Federal agency manager: *Agencies report that funding research spent in EHS in NNI is 5%, but in my opinion it is only around 3%, because there are some stuffs that are reported that are not necessarily EHS research, some are applications. We would like to see 10% of NNI budget be spent in EHS research.*

The EHS research in the US has direct relationships with agriculture and food production. For instance, studies that seek to understand nanoparticles behavior when they are in contact with the environment, and how these nanoparticles interact with the ecosystem are key factors that could affect the interaction with natural resources required in food production, such as soil and water. Coalition A Pro-EHS subgroup members recognize the role that government needs to play in allocating public funding in EHS research. Furthermore, they believe that with more reliable information respect to nanoparticles can reduce public concerns and promote industry engagement in nanotechnology research and development.

"We (researchers) have these grantees meetings with those industry people. They always see the negative effects. All of them say if you have a nanostructure in your package and in your life, maybe society will rise some questions…people always think that nanoparticles are toxins for the environment. This is a wrong message. The right message is to analyze what kinds of nanoparticles have negative and positive effects."

The idea of increasing EHS research funding can mitigate the potential negative nanotechnology effects, which is shared by members of this subgroup. But other researchers who work in applied research disagree with the idea of this subgroup in term of reducing funding from their research area, which have already inadequate funding sources, to distribute these few resources to study nanotechnology EHS issues.

The goal of conducting nanotechnology research that can contribute to sustainable development among pro-nano advocacy group is only observed indirectly through the influence of two subgroups. The pro-EHS subgroup that as I said it try to influence policy makers reducing potential negative effects of nanotechnology in the agrifood sector, and with that goal in mind the technologies developed could be more sustainable in terms of mitigating negative environment impacts, and producing healthy food that allow improve the quality of life of the population. One researcher members of this subgroup explained in the following sentences the link between nanotechnology research and sustainability:

“I think there are ways to optimize pesticides and produce much more food in a sustainable manner for a growing population. There is only one planet. There will be no business for anybody if we fail as a society.”

Another researcher that has been involved in sustainable research before nanotechnology initiative started mentioned in the interview that NNI has considered recently the concept of “sustainability” in their aims, just in a more rhetoric manner, due to they have not taken concrete actions to connect the nanotechnology research with sustainability development, as he said:

“I think that they (NNI) are using the concept of sustainability because they are force-feeding. In other words it is a thing to do, but they do not take it on deep consideration”

The second pro-nano sub-group that has recently been formed is the one joined by members who are researchers that are utilizing biodegradable nanomaterials produced from agriculture and forestry raw materials, such as cereals and soya beans scratch nanoparticles and wood’s nanocellulose.

5.3.3 Bio-base nanoparticles Advocacy Subgroup

This subgroup has emerged in the last few years, thank the federal research funding support in the USDA NIFA and more recently the Forest Service which started its nanocellulose research funding program in 2006. Members of this subgroup are advocating with federal agency program managers to increase the research funding for natural platform to produce natural polymers, which can have several applications as nanosensors and biodegradable materials, they promise higher benefits than other nanotechnology devices as nanometalic particles. Even more, they believe that natural nanotechnology platform can contribute directly to sustainable development, because they reduce the use of synthetic polymers commonly used in manufacturing industry, which are a source of pollution, and require more energy to be produced. Some of the advantages highlighted in the interviews with them are presented in the following table:

Table 9: Beliefs Subgroup Bio-base Nanoparticles

1. Reduce risk of cell toxicity:
"Biodegradable nanomaterials have the potential to revolutionize nanotechnology internally, because instead of using carbon nanotube, silver particles, and gold particles, we are using cereal particles a system very friendly, which is not toxic, this is grass that has been proved to be safe so we also contribute to the evolution of nanotechnology. It is more sustainable."
2. Biodegradable and Friendly with the Environment:
"Some colleagues are looking at the toxicology of edible and biodegradable nanomaterials and interestingly we have found that cells utilize these material as food instead of being toxically affected by nanoparticles, they contribute to the energy requirement of cells, it is a very promising opportunity"
"Nanocellulose is a renewal nanomaterial trees growth as cellulose, we are extracting it from trees, and this is an advantage."

“Capability of nanocellulose to store carbon, the trees store carbon, when harvest a tree carbon is still storage in that product until the end of the life product, if you recycled them. When the carbon is recycled it reduces emissions of green house gas.”

3. **Improve Social Benefits to Farmers, Forest Land Owners and Consumers**

“We are hoping that this will provide value to forest land owners, we can extract this material from lower wood”

“The livestock producers, because all the nutritional efficiency strategy held the potential to reduce the quantity of protein to feed animals”

5.4 Resources Pro-nano Advocacy Group

The Advocacy Coalition Framework developed by Sabatier uses a typology of policy-relevance resources that members of a coalition can use to influence policy process. This typology describes six types of resources, each of them is evaluated in the Pro-nano coalition group in the following table:

Table 10: Advocacy Pro-nano Coalition’s Available Resources

ACF Resource	Pro-nano Advocacy Coalition Resource is Available?
1. Formal Legal Authority to make policy Decisions	Yes: This advocacy group has members that also are agency officials in charge of administrating the research funding. They are in a better position to make lobby with other superior government actors and

	legislators to increase agrifood nanotechnology research funding resources.
2. Public Opinion	No: the public in general has not formed an opinion about nanotechnology, so they do not necessarily support this coalition.
3. Information	Very few: the information respect to agrifood nanotechnology is very weak. It is difficult to show that the potential benefits from this technology, because it is an early stage of research and development.
4. Mobilizable troops	No: This coalition is mainly formed by researchers and some federal agency managers. They have lack of public power demonstration.
5. Financial resources	Very few: Mainly for competitive grant programs. They have resources to organize scientific conferences, grantees workshops, and some material for diffusion in media and newspapers.
6. Skillful leaders	Yes: among the coalition members there are some of them have decision power over the distribution of funding, define research priorities in the sector, and capacity to establish links with the industry.

5.5 Relationships among Pro-nano coalition's members

The Pro-nano advocacy groups are very active participating in conference and workshops organized by federal agencies and professional societies. During these conferences grantees get out reports from their research and also offer some suggestions in regards to potential new research areas in which the federal agencies should start to think on. This interaction among scientist and agency managers is observed in the following sentences:

Researcher 1:

"I think this is a more to hearing type conference, to get lessons from scientist and see which area we should concentrate. Food safety, detection, interventions, and now they are looking into side effects"

"We do have session in the meeting for instance in the Institute of Food Technologist (ITC) which is a professional society for food scientists, and we discuss about our research every year."

Agency Manager 1:

"We organize annual grantee meetings, as part of the stakeholder; we work with professional societies putting some conference and symposium this is an opportunity to scientist to present to other scientists from other countries to find solutions to the agrifood sector."

" I was invited to represent International Union food Science and Technology IUFoST"

"We share the outcome in these conferences with companies, and we set precompetitive resources in collaboration with other government agencies such as NSF"

Agency Manager 2:

"The Agenda 2020 has a research roadmap for forest products and pulp and paper with a component in nanotechnology, which is explicitly part of the agenda looking for emerging technologies and products. We also work closely with some of the private

industry groups. We do not have direct money to investment from the private sector. We try to work together to establish research goals for the entire forest product sector, we used that and we try as much as we can match our research funding with that."

The stakeholder interaction of federal agencies has mainly consider researchers and industry's representatives, only recently some public interest groups have been invited to discuss their arguments and views with respect to agrifood nanotechnology. For instance in 2009, a group of individuals from the scientific community, the food industry, government agencies (USDA, EPA, NIH, and FDA), public interest groups and scholars met in a workshop called" Impact of nanoscale technologies on agriculture and food systems: a scoping workshop for assessment of technological and societal implication." The following themes were discussed during this conference: the benefits from this technology, the needs for greater understanding nanotechnology in agrifood respect to safety, regulations, increase engagement with public, and the insufficient public financial support to research and development of agrifood nanotechnology.

The workshop agenda was clearly influenced by the participation of environmental NGOs, who utilized the case of biotechnology development to construct their points of concerns respect to nanotechnology applications in the agrifood sector. They think that nanotechnology could potentially come in the same path as biotechnology, unless they prevent that to happen. Some of their points were; guarantee more safety, technology accessible to poorer nations, ecological sustainability, intellectual property-transparency, and access to the information about products and methods.

Federal agency managers have been willing to share ideas and views with social actors like some NGOs as ETC group to identify together the benefits the broad society, and with that to increase technology adoption by the users and consumers. But others pro-nano coalition members disagree with the previous idea of sharing the views with NGO's and other social activists. Because they see the actions of environmental NGOs as an antagonist group that exaggerate the concerns, provoking fear and affecting the allocation of federal funding for nano-research programs, waste of valuable time, and affecting a loss in competiveness in relation to international competitors.

Researcher 1:

"The unknown is the cost and they (NGOS) can always use "safety" as a base to justify a slow down or a moratorium. They are against this technology because we do not need it, what is the benefit? We have been living for many years without nanotechnology in food and agriculture so why we need it?, and what are the potential for health effect are totally unproved, it is hardly to anyone to prove that it is 100% safe, so they basically say we do not see enough benefits to justify that particular risk."

Researcher 2:

"The NGOs have never engaged with scientist or actually working in the field and they come from a position of fear. I think that we try to look at all sides of the problem, but somebody's rejection on the full technology is stupid."

Agency manager 1:

"I think that particular group has different social angles, for instance the aspect of cutting edge technology could replace the current technology, international market

accessibility, and international harmonization on regulations"

Pro-nano advocacy members recognize environmental NGOs as a rival coalition, which have differences in views and expectations with respect to nanotechnology research. On one hand, Pro-nano advocacy group emphasizes in the potential benefits from nanotechnology research. On the other hand, the NGOs make the point on risks. In the following section I will illustrate this new advocacy coalition, I will show their members, set of beliefs, resources and interactions, to influence the US agrifood nanotechnology public research agenda.

5.6"Pro Nano-Regulation" Advocacy Coalition B

After the first years of the national nanotechnology initiative implementation in the US, the pro-nano coalition was the only one that was actively operating in the US, which advocated for increasing public research funding toward agrifood nanotechnology. They visualized a tremendous potential from investing in this research area that could benefit the agrifood sector development and other related industries. They succeed in influencing policy makers to establish annual funding programs in federal agencies, specially the USDA, which established competitive grants program that promoted the research groups formation to nanoscience and nanotechnology investigations. But they failed in term of the allocation of financial resources to achieve their research goals, because the federal funding money was less than they expected.

At first stages of nanotechnology initiatives in the US, the industry also shared the optimistic view of the pro-nano coalition with respect to the huge potential that nanotechnology offered to the sector. But soon later the industry became discouraged to conduct collaborative research with universities. Furthermore, the industry stayed silent about their in-house nanotechnology research, they feared of increasing the public concern and rejection to use this new technology. Social organizations as environmental NGOs played a key role in the beginning of safety nanotechnology debate. In 2003 was published the first of several reports from NGOs that called for more transparency, regulation, and public participation in the nanotechnology debate (ETC Group 2003), with this attempt to rise the concerns from civil society organizations as the author of this report joined in an advocacy coalition group formed by members from other NGOS, worker Unions, and consumer organizations. This coalition is not against nanotechnology per se, but they claim for a clear regulation framework for the new technology, more transparency of all actors involved in the technology from policy makers, researchers, and industry, and higher public participation since early stage of nanotechnology research and development. For instance, the statement of ETC group on nanotechnology in their report of 2003declared "*The point is not that technologies are bad (although certain technologies maybe inherently destructive, centralizing or otherwise dis-empowering). Rather, the evaluation of powerful new technologies requires broad social discussion and preparation. Society must be informed and empowered to participate in decision-making about emerging technologies.*"(pg. 1)

Since 2005, ETC group together with other NGOS as Friend of the Earth, Center for Food Safety, the International Center for Technology Assessment (ICTA), and

Environmental Defense have advocated for a regulatory reforms that consider new regulation to nanotechnology products. In 2006 this coalition made a formal petition to FDA to control products that contained nanoparticles[14]. Additionally, ICTA and the Center for Food Safety (CFS) filed a legal petition with the EPA on behalf of a coalition of 14 public interest organizations calling on EPA to regulate nanosilver and other nano-pesticide products. In 2011 the same coalition after not receiving formal response to their 2006 petition filled the first lawsuit against FDA about the health and environmental risks of nanotechnology and nanomaterials[15]. Only after six years after the first petition, in April 2012 FDA gave official response to the first advocacy coalition pro-regulation petition[16].

In the following sections of this chapter I will analyze this coalition under the Advocacy Coalition Framework approach utilizing the data obtained from the semi-structured interviews with key-actors of the US agrifood sector, to study the members of this coalition, their beliefs, actions, and resources to achieve the group goals of increasing understanding and control in regards to nanotechnology research and development.

5.6.1 Beliefs of Advocacy group Pro nano-regulations

The coalition´s members are not against the use of this technology. Nevertheless, they are not in favor of applying nanotechnology or any kind of synthetic devices in the food that they regularly consume, as was mentioned by one of my interviewee:

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[14] "Petition Requesting FDA Amend Its Regulations for Products Composed of Engineered Nanoparticles Generally and Sunscreen Drug Products Composed of Engineered Nanoparticles Specifically".
[15] http://www.centerforfoodsafety.org/wp-content/uploads/2011/12/1-Pls-Complaint.pdf
[16] http://www.icta.org/doc/Andrew%20Kimbrell-FDA-2006-P-0213-Citizen%20Petition.pdf

"I do not see making food more synthetic and more from the laboratory as an advantage…"

They show a remarkable difference with respect to the pro-nano group about the benefits from nanotechnology. Actually they see more risk than benefits coming from nanotechnology uses in the agrifood sector. Therefore, they have called for a moratorium on further commercial launches of food products, food packaging, food contact materials, and agrochemical that contain nanomaterials, until new specific nano safety laws are set up by federal regulatory authorities.

NGO's member 1:

"I am not against technology, I use technology it is all around me, I just want to make sure it is done correctly and the people need the right to feel safe with this stuff"

NGO's member 2:

"They can create something cool but it can also could cause cancer, or affect the environment, we see many red flag studies in which we do not see the government supporting those kinds of studies in the academia. We see more about the economic benefits, but in the long run the economic benefits let going to be looking for these issues, for the sustainability."

NGO's member 3:

"Nanotechnology is one of those really cutting edge issues which are not collected by the

main stream media. It is not really talk at the big NGOs level, with a tremendous potential benefit but also uneven outcome through bio-pollution, unintended human health exposure, or perpetuation of inequality economic situation…"

Pro-nano regulation group's members share the same worry that society repeat same mistakes that happened in the past with the introduction of previous technologies without an early study of potential negative consequences, such as the introduction of asbestos or the use of GMOs in agriculture. In the first case they realized about some similarities on risk associated to the use of asbestos that provoked severe health problems to whom get in contact with, this idea was pointed out by one of the member as the following paragraphs:

Worker Union's representative:

"*We need to take a precautionary approach, so that we reduce or eliminate as much exposure that we can while this new technology is evolving so we do not have the situation where 20 or 30 year later we have carbon nanotubes causing lung cancer just like asbestos"*

"We want to have a perspective to say that we have some evidence that carbon nanotubes are unsafe, and there are some evidences that they have the same properties like asbestos, but we do not have a full set of information, and we do not have a human who have been injured or have sick or got cancer, so we need take some precautionary measure to make sure to control the exposure the best we can."

In the second case about GMOs in agriculture, their argument is that after several years of using GMOs in crop production they do not clearly perceive benefits to the society, and that is a sufficient reason to build a strong opposition to the use of those technologies as well as nanotechnology until real benefits become evident. Even more, members of pro-nano regulation coalition that also takes part in coalitions of other policy subsystems such as biotechnology research, conduct campaigns against the use of GMOs because they believe that the only one that has taken benefit from the technology are few transnational companies that have made profit selling more expensive seed and huge amount of agro-chemicals to produce effective use of GMOs. This argument is observed from one NGO member that quoted the following sentences:

NGO´s member 1:

"We do not see any GMO crop on the commercial level that really do anything more than sell more pesticides, there is not benefit to the environment, to human health, to farmers and consumers."

NGO's Member 2:

"We do not oppose to GMO food all together, but currently practices show that there are no reasons to us to support it. So we really feel that at this point the Federal Government with which we are more involve regularly than the private sector must have the role to evaluate these new nanomaterials"

With these two arguments of not verify benefits from GMOs technologies and the potential risk from using nanoparticles are unknown, pronano-regulation members sympathize with the idea of establishing regulations on nanotechnology development, giving more legal tools and power to federal agencies such as EPA and FDA to assure the safety of new nanoparticles before those are released to the environment or getting in contact with people.

Since several years of the national nanotechnology initiative has been putted in place and after plenty of public money has been supplied to supporting nano-research practices, members of this coalition protest for a lack of regulatory framework that guides the nanotechnology research and development in the US.

"One of our biggest criticisms right now is that none regulation agencies has promulgate new regulation that it is specific to nanotechnology, instead they are applying old outdate status to these new technology. It doesn't fit very well and sometime does not work at all."

They think that it is not possible to conduct the so called "good science" if policy makers are breakthrough biased toward finding potential economic benefits and not taking much attention in studying potential risks.

"I try to keep my opinion and really see the both side of science, and I think that we can do so much more, even when we can capture the benefits of these technologies potentially I think we have the right to explore in this world to growth and create things

but we have to know that we have responsibility in this globalized world we have to be coordinated in some ways"

The pronano regulation members believe that they need to take actions in the nanotechnology debate because they see a lack of information about products that are already in the market which contains nanoparticles and have not been proved if they are safe, neither for workers who manipulate nanoparticles in manufacturing processing, nor for final consumers that will be expose to them. Their argument is that federal agencies in charge of regulate new nano-products have failed to do the control and protect the environment and people from potential risks from nanotechnology. This coalition made its first campaign on nano-regulation in cosmetics, with the goal of reviewing the cosmetic law and updates the regulations to effectively control the use of nanoparticles as titanium dioxide (TiO2), some of these arguments are presented in the following sentences from interviews with NGOs members:

NGO member 1:

"The issues of cosmetics regulation is recently been debated and a hearing took place three years ago, it was the first in 30 years, we found in shampoos mercury in face creams, and other ingredient beyond nano, in the hearing one of the leader in FDA testified and he said that need funding to test new products as nanotechnology and they have novel properties, so they even speak to support more funding:"

NGO member 2:

"We want to EPA use the authority to collect the data before approval in order to protect

workers.

Pro-nano regulation beliefs that the industry is not working with transparency about their in-house nanotechnology research and development activities. This silent environment in the industry sector respect to nanotechnology is evidenced by several coalition's members that are worried to observe a lack of legal enforcement to conduct risk assessment to new nano-products, with institutions that do not have power to regulate and control these new products. This perception of lack of transparency in the industry is pointed out by several members of the pro nano-regulation coalition, some of these arguments were expressed in the interviews conducted to members of this coalition in the following excerpt:

NGO member 3:

"They do not what to talk what they (companies) are doing at the R&D stage, but it in this stage where we need to think about safety."

NGO member 4:

"Nanotechnology is been developed by Monsanto, Syngenta so is very concentrated in few big companies, it is impossible to get information from them. We know about Syngenta because they said that they are working but now we do not know"

"With the nanotechnology campaign I did not start thinking that it is something negative, I really want to start thinking that this is very powerful …. But there is potential for more,

and companies are taking just a short portion of this new power. I still see some positives coming from this industry but at the same time there is need for so much transparency."

The transparency does not only refer to know more about what the industry is doing in relation to nanotechnology, but also how they communicate this information to the public, because public know very few about it and they have the right to know the benefits as well as the potential risks from product that contain nanoparticles. This point was mentioned by some of my interviewees, as the following ones:

NGO member 1:

"To be honest I think it is not fully on the market yet, but we do not know, I am purely guessing, we know it is going to be coming, there are up to 600 nanofood and 500 nanofood packaging out in the market. We have some evidence of that, nanofood is suppose to be worth an estimated of 6 billion dollar if not more, so it is out there, we know that chemical and agrifood companies like BASF, DuPont, and General Mills are investing in this and it will be an issue and consumer need to be informed."

NGO member 2:

"*I like to see people more in power and less attached to fear, and I think that many people even our regulators deal with fear, and fear about what other people would think sometime stop what they feel is right."*

The pro nano-regulation coalition put forward the lack of regulation framework on nanotechnology to reduce potential risks, the lack of transparency and information about the industry agenda in nano research and development, and scarce public participation on discussions about the type of technology contribution from nano science research, all these arguments produce among the coalition members the incentives to work together in achieving their group's goals of influencing US policy makers to focus the research funding more to basic science than applied research . Because so far, they see that most of the federal funding goes to support research and development of new nano-products giving more competitiveness to the local industries, but very few of this funding is oriented to study the nanoparticles interaction in the environment, their effect in the human and animal health, and safety issues related to this new technology. This coalition think that the government agencies are the ones that need to guarantee a more sustainable contribution of emerging technologies as nanotechnology, with emphasis not only in economic dimensions but also taking care of the environment and the technology's impact in the society, this idea shared by the coalition's member was explained in the interview by two members in the following table:

NGO member 1:

"Most of these budget go to research and development for new products and not very much going for safety testing, we like more money for safety testing and money going to making sure that the product that are been developed have been developed as safe as possible." ……"The Public sector must do this work (EHS research), it is not the

industry who is doing that."

NGO member 2:

"Public sector and public dollar taxpayers should be speeded in benefit the public; we do not want public money going to materials and products that potentially can cause public concern, environmental concern or public health concern."

NGO member 3:

"We want regulations that ensure that these stuffs are labeled, I think that it is the basic right and also we want that government spend more in EHS, currently 2 billion a year is spent by government in nanotechnology research, and only 2 to 4 % is spending in EHS studies. So we are calling for more money invested in safety research, for this technology and these products cannot be in the market unless we know that they are safe."

Although this coalition has been very active in trying to influence the public research agenda in agrifood nanotechnology, they feel that they have less opportunities and power to influence the research agenda than the pro-nano coalition. For instance one of the coalition members mentioned in the interview the following:

"NNI have been very resistant to NGOs participations, they have not opportunities and interest to engage with NGOs, their interest is in getting the public to trust in the technology, so then they can get to the market and staying competitive and not letting China to get ahead of us."

The power asymmetry in influencing the federal budget with respect to the rival coalition is taken with more evidence from the following comment of one member of the pro nano-regulation coalition:

"The problem is that all the independent scientists that are reviewing the budget and guiding the federal government have also patents and have started companies, so their priorities with federal money is to get them safely across the wasteland zone from laboratory to company, that why they see their priorities, I do not think that they should be advising the federal government as an independent scientist if you have a patent and started a new company."

The pro nano-regulation advocacy group put in evidence a conflict of interest that is represented by the scientists that participate in the shaping of strategies and roadmaps for nanotechnology development are the same members of grant recipients. Therefore, the research topics that receive more funding are those that the agrifood research community currently is working with. This endogeneity works as a barrier to the entry of new actors into the research agenda. The exception to this focalization of research to only few topics is the introduction of EHS research in the agrifood sector. The prioritization of conduct research about potential risk and safety issues in agrifood sector was born as a consequence of the concern rose by the pro nano-regulation groups and also from the interest of the pro-EHS subgroup of the pro-nano advocacy coalition. This factor can explain the scare research attention that has received sustainability issues, due to the absence of an advocacy group that can raise the flag to support sustainable development in the time research funding are designed.

In my research I found evidence of an early stage of a pro nano-regulation sub-group formation. This subgroup is formed by organic farming organizations, even though they are not directly involved in the nanotechnology debate, they follow the discussion with high interest, because they do not want to see some negative effects from nanotechnology that can impact negatively in their production system, they see nanotechnology as synthetic process that cannot be applied to organic production system.

5.6.2 Resources Pro Nano-regulation Advocacy Group

The Pro Nano-regulation coalition group shows differences with respect to the pro-nano advocacy group. In special differences related to financial resources. The public funding that are mainly available in competitive grants for the scientific communities so far have not considered the participation of researchers and policy analyst from NGOs in their call as valid grant recipients. Hence, these social organizations have search financial support in other places as foundations and philanthropy sources. But clearly, they have few resources to conduct their campaigns, as is represented by the comment of one of the interviewee:

"We do get funding from our board and other spot, you know donations but really our funding is also at nanoscale. This is like keep me alive funding. We have yearly contract, I have able to fund my work from the past 5 years, and it can become very stable, but at the same time we have not working with that much money."

The lack of sufficient financial support to conduct the nanotechnology campaign is a common sample for all the members of the coalition. Some NGOs with more international presence have more stable resources to maintain the salary of a policy analyst who usually is in charge of lead the campaign, but other social organizations such as worker unions have less financial and human capital resources to lead the campaign. These secondary organizations receive information from the organizations leaders, but they do not receive financial support from them, this dynamic of sharing mainly information but not funding was observed in a piece of interview with one of the members of this coalition:

Interviewer: How do you organize with the other NGOS?

NGO Scientist:

"Different people are doing different stuffs, actually the food stuff is more done by ICTA, and consumer unions do some, unions not very much."

Interviewer: Do you share resources with other NGOS?

NGO Policy Analyst:

"Not really other than our materials. When we publish our own reports and sometime we collaborate with other organizations that make another part of the research, which include legal and other expertise into the report, and some time we do join release, we send it to our press contacts."

This typology describes six types of resources, each of them is evaluated in the following table:

Table 11: Advocacy Pro Nano-regulation Coalition's Available Resources

ACF Resource	Pro Nano-regulation Advocacy Coalition Resource Available?
1. Formal Legal Authority to make policy Decisions	No: This advocacy group lacks of members who are agency officials in charge of administrate the research funding.
2. Public Opinion	No: the public in general has not a formed opinion about nanotechnology, so they do not necessarily support this coalition.
3. Information	Yes: Press release, blogging, reports, speeches, and communication with that participate in NGOs and worker affiliated to Unions.
4. Mobilizable troops	Yes: The NGOs have voluntaries and common people that sympathize with their campaigns and fill mass comments to be send to Regulation Agencies as FDA and USDA, and in the case of unions they have direct contact with their affiliated workers associations that can become very active if is it is required.
5. Financial resources	Very few: from their board, donations and some funding organizations as the CS Fund.
6. Skillful leaders	Yes: Skillful personnel with educational background in topics that allow them interact regularly with policy makers and researchers. But with time constrains due to their participation in other campaigns as GMOs, Pesticides regulation, Cosmetics, and Synthetic Biology

5.6.3 Relationships among Pro Nano-Regulation Coalition's Members

This coalition group presents a more structured organization with respect to the pro-nano advocacy group. Even though this advocacy group has scarce economic resources to conduct their pro-nano regulation campaign, they overcome this weakness with a better coordination of actions, distribution of roles, and a more active communication among coalition's members. There are distributions of tasks in relation to the strengths of each member, for example, some of the environmental NGOs policy analysts that have more experience in the legal arena are in charge of preparing the law suits or any other legal action that require a deeper understanding of laws. The organization inside of the coalition is evidenced in the following excerpts:

NGO member:

"We have a coalition of vary sort of organizations that are interested in this issue, we get the research and public dissemination material to inform the public and policy makers. we gather the science and make a case for regulation, transparency and a real adult mature consideration of this technology, we get together to strategize, we have campaigns focus on those nanomaterials that are included in things that people become more contact with, such as food, sunscreen, and cosmetic."

"We have campaign strategies in place, we share information and key ways we can best highlight this information to the public and to our government to take action."

After the document is ready, it is shared with the rest of the coalition members who review and offer feedback before sending the document to other social organizations that could be interested in being part of a specific campaign. In some campaigns that have more specific focused on a particular issue or which involved a broader scope of the problem that enlarge the size of the coalition by inviting other organizations that are not actively participating in the coalition to engage with them into the campaign and sign legal petitions. This characteristic transforms the pro-regulation coalition into a more flexible structure of the coalition, increasing the number of supporters and strengthens their claims with a higher number of organizations that sign the documents, this type of organization is presented in the following interview's comments:

NGO Policy Analyst 1:

"Usually the same people would be interested, small handful group of people, but often time we get other organizations and stakeholders get involve."

NGO Policy Analyst 2:

"We do our research and we share and we talk about it, and we see what ways we will use to get to the public, which journals, and who will get our information out there, so people can become informed, and policy makers can get the other side of the coin and make judgment."

5.7 Conclusions

The study of advocacy coalition framework applied to the US agrifood nanotechnology policy subsystem found the presence of two advocacy groups. The first one, which I called the Pro-nano group composed mainly by researchers and some federal agencies managers who share an optimistic view related to the potential contributions that nanotechnology research can offer to the sector and the society in general. This policy core beliefs is the stickiest glue of the coalition whose members work together in order to influence policy makers about the necessity to invest more public funding in agrifood nanotechnology because it is worthier in several types of applications that can improve crops production and produce more healthy and better quality food, that will impact positively in the US economy and the population. The current insufficient US research funding has limited the development of the sector, losing the leadership position that the US research occupied at some point in the middle of the last decade, with the rise of China as the leading country in agrifood nanotechnology. The unfunded public agrifood nano research has provoked a loss on competitiveness that should affect to all sectors in the near future.

The second advocacy coalition that I found in my thesis research was the “pro nano-regulation” group, this coalition is formed by social organizations such as environmental NGO’s and worker unions mainly. They have a different believe respect to the potential contribution of nanotechnology in the agrifood sector with respect to the pro-nano coalition. Pro nano-regulation members share the worry of a lack of a regulation framework that governs nanotechnology research and development in the US. They perceive it is very risky to invest public funding into a research area that offers more unknown consequences than potential benefits. They advocate for more transparency of the nanotechnology research and development, with the group's goal of promoting a shift from the current nanotechnology research agenda direction oriented to applied research toward a new research agenda focus more on basic research. With a special attention on research funding rise on environment, health, and safety research (EHS), which currently its 5% of the annual NNI budget in not enough. They believe that it might increase at least over a 20% per year. This change in the research agenda should reduce potential risk associated to nanotechnology and as a result it reduces their concerns in regards to the use of gold, silver, and copper metallic nanoparticles, as well as the use of carbon nanotubes that could cause severe human health similar to those ones produced by the use of asbestos in the past.

The public nanotechnology research agenda in the US has not received a particular attention in regards to sustainability. Only indirectly, during the last years the nanotechnology debate has emphasized on potential risks associated to nanotechnology and find scientific solutions to reduce them. Consequently, a crescent agreement among members of both coalitions related to the necessity of investing more public funding in EHS research has come into sight. This agreement among members of the two rivals' coalitions started to emerge in 2006, year in which the pro nano-regulation coalition was more active trying to influence the research agenda toward more regulation and EHS research funding. During that year a subgroup from pro-nano coalition called the pro-EHS research group was formed by environmental and social scientists and some agency officials that are in charge of the EHS program from federal agencies such as EPA, FDA, USDA, and NSF. They had a lower level of coordination with respect to the pro nano-regulation coalition, but they shared a similar set of beliefs and arguments about an unfunded EHS program, and with a higher position in relation to legal authority to influence upon the research agenda toward getting more EHS research fund. At the time when these groups shared the thought about reducing risk nanotechnology by investing more in EHS research matched with the time of a real increase in agrifood nanotechnology EHS research, this raise was a finding that I illustrated in Chapter 4 where I analyzed the US agrifood nanotechnology research agenda in the last decade.

The rise of interest in EHS issues could be in the short run beneficial to the establishment of sustainability issues in the core goals of the US agrifood research agenda. Moreover, since the second half of the last decade, a new topic of research has emerged based on the use of nature-biobase nanoparticles from agriculture crops and forest woods raw materials. The replacement of controversial nano metallic and carbon nanotubes by the use of natural- based biodegradable nanoparticles open opportunities to produce a shift in the US research agenda toward more sustainable development.

With the shift of the research agenda toward more sustainable development the concerns from the pro-regulation coalition can be diminished, but this shift not necessarily brings with it a scenario to legislate a particular regulation framework to nanotechnology research and development. This point of concern that is in the pro-regulation deep core beliefs probably will remain without not much change over a longer period of time, probably until an external shock affect the policy subsystem, for example, the confirmation of scientific evidence that nanoparticles really affect the environment, human health or workers' safety. But until no new relevant information is confirmed the regulation framework will remain the same. In the following chapter I will present the results of the analysis of documentation respect to US nanotechnology research, complemented with the analysis of Congressional House Hearing conduced in the last ten years which study the role that these two coalitions have been playing to influence it towards each coalition interests.

CHAPTER 6.

US AGRIFOOD NANOTECHNOLOGY RESEARCH AGENDA AND ITS INSTITUTIONAL FRAMEWORK

6.1 Introduction

The institutional framework that sets the rules of nanotechnology research and development has been under criticisms since early stage of the National Nanotechnology Initiative creation. This chapter does not pretend to study the content of the regulatory framework, this analysis has lately been conducted by other scholars (Taylor 2006; Suppan 2011), who recognize an absence of US regulation framework for agrifood nanotechnology, although some federal agencies have recently published a draft guidance for industry and oversight nanotechnology which does not conduct to a regulatory approach because of its voluntary adoption. This lack of a regulatory framework was pointed out by the report published by the Institute for Agriculture and Trade Policy (2011) that quoted the following*: ".. none of these products (agrifood) are regulated by U.S. federal agencies. Research and development for agricultural and food applications of nanotechnology has expanded rapidly in recent years, with over $50 billion in global public investment and at least as much in privately funded research. At least 1,300 products with Engineered Nanotechnology Materials (ENMs) have been commercialized, despite myriad uncertainties about the public health and environmental effects of ENMs." (pg. 3)*

Hence, not much change has been observed in the regulatory policy of agrifood nanotechnology since the beginning of the National Nanotechnology Initiative in 2000, rather than focusing my analysis of this chapter about the evolution of an almost non-existent regulation framework in United States, this chapter seeks to evaluate the role that each coalition has played in influencing the institutional framework by which the agrifood nanotechnology has been developed during the last 10 years. To evidence the influences and actions conducted by coalition members was necessary to study several government reports, regulatory agencies' documentations, and congressional house hearing related to nanotechnology.

Regulating nanotechnology has been part of the core debate among the two advocacy groups presented in the previous chapter. On one side, pro-nano coalition members have tried to influence policy makers to increase the federal funding oriented to the enhancement of the potential and evident economic benefits that this technology carries on, giving more competitiveness to the food industry and contributing to job generation. On the other side, pro nano-regulation advocacy group has claimed for more action by the regulatory authority as EPA and FDA, which have shown an incapacity to monitor the generation and commercialization of new nano products that are available in the market without any type of risk analysis that assure the safety of new products. In this chapter I will present the results of the study of actions taken by advocacy coalitions in public hearings offered by US Congress and other federal agencies. The goal of this chapter is to illustrate the evidences of the actions conducted by each advocacy group in regards to influence policy makers. The analysis of 20 documents that contain official reports and congressional house hearing, which have been published through the last decade, allowed me to determine if the existence of the two coalitions of the agrifood nanotechnology policy subsystem also play a relevant role in influencing policy makers.

6.2 Advocacy groups Participation in the US Nanotechnology Research Agenda

Since the establishment of the US National Nanotechnology Initiative in year 2000, there have been several opportunities in which public interests groups have participated giving their testimony in the Congress and federal agencies about their views and concerns of the US nanotechnology research agenda development. They have shared in these meetings their beliefs and arguments with respect to different issues of the nanotechnology research agenda in the US, such as financial allocation of funding, the type of research needed, and the government role related to EHS research, among others.

The “21 Century Nanotechnology Research and Development Act” was signed by the US President in December 2003 by which assured the federal funding sources to conduct interagency programs on nanotechnology R&D. The main argument to Congress allocate federal funding was the recognition of the relevance that nanotechnology has to ensuring the US scientific advancement to take the world leading position on this emerging technology. At that time, nanotechnology was considered the most promising research area of contribution to the US economy, with a potential to grow up the industry productivity and the US global competitiveness. However, sustainability issues were not mentioned by the system actors during the first stages of agrifood nano development.

The potential benefits were also early recognized by different actors in the agrifood sector. Therefore, as expected the main actors involved in the policy discussion during the first years of the NNI creation were researchers and industry representatives. For instance, the USDA nanotechnology roadmap workshop of 2003 was composed by university researchers, federal agency managers, and some food industry representatives. Similar type of participants were invited to Congressional House Hearing (CHH)by the Subcommittee on Research & Science Education on May 18, 2005 called "The National Nanotechnology Initiative: review and outlook" in this congress hearing four witnesses participated, three universities' researchers and one General Electric representative. They gave response to Congress questions mainly related to know fields that are perceived as the highest opportunities of economic and commercial development, and the biggest positive impact on the US work force that nanotechnology offers. For instance, one university professor mentioned the benefits from adding nanoparticles to fibers that can make them stronger to be used by food processing workers that require handle sharp materials like glass or sheet metal, or the benefit obtained from smart plastics for preventing spoilage in food packaging. These types of claims that emphasize the benefits from nanotechnology and the necessity for more research funding match with the arguments presented by pro-nano coalition members. The participation of these coalition members is shown in the following section.

6.3 Pro-nano Coalition Participation in Influencing the US Nanotechnology Policy Subsystem

Just one month after the CHH reviewed the NNI, the109thCongress House carried out in June 2005 a new hearing to analyze what was the US nanotechnology R&D position with respect to other countries and what factors most influenced the US performance in this field. During this hearing there were four witnesses, a member of the President's Council of Advisors on Science and Technology (PCAST), two industry’s representatives, and one venture capital firm representative testified. All of them were very proactive in advising Congressmen’s with regards to the necessity of increasing funding support to the US nanotechnology research and development. The argument used by one of the witness was the lack of appropriate funding that provokes a lost in leaderships in relation to other countries, this idea was expressed in the following piece of the presentation given by the Lux Research Inc representative:

”Now, let us start with the good news. The U.S. leads the world in nanotechnology today. Last year, $4.6 billion of government spending went into nanotech R&D worldwide. However, our lead is tenuous. The rest of the world is catching up. We are falling behind in government investment. At purchasing power parity, Taiwan, Japan, and South Korea all exceed us on a per capita basis.[17]*”*

Similar argument was expressed by Motorola Inc. representative who argued that nanotechnology research offers remarkable potential for innovation that could allow the US industries to maintain the global leadership in many sectors. These two industry members clearly share the core beliefs of the pro-nano coalition found in the previous chapter, but they are not necessarily advocating for agrifood nanotechnology research. Even though, the venture capital representative recognizes the multidisciplinary of nanotechnology that can almost benefit all industries, from aerospace, energy, health care and agriculture.

[17]http://www.gpo.gov/fdsys/pkg/CHRG-109hhrg21950/pdf/CHRG-109hhrg21950.pdf

The role that played industry representative influencing policy makers since the first congressional hearings about nanotechnology development is observed in the witness of the NanoBusiness Alliance. This trade organization of emerging nanotechnology industry that is self-defined as the premier nanotechnology policy and commercialization advocacy group in the United States. This advocacy group was composed by start-up companies, Fortune 500 companies and academic research institutions in 2005. They believe that “nanotechnology will be one of the key drivers of business success, economic growth, and quality-of-life improvements in the 21st Century. The Alliance provides a collective voice and vehicle for efforts to advance the benefits of nanotechnology across our economy and our society.”Moreover, his representative was one of the first to claim about potential benefits from nanotechnology linked with sustainability issues, as renewable energy generation that can make the US “the last superpower” be the world leader in nanotechnology commercialization. Nevertheless, the initial active participation of this industrial alliance in the nanotechnology debate, years later they seems less active with few activities, for example the last one they organized was the annual conferences which took place in Chicago in 2010.

The PCAST that act as the National Nanotechnology Advisory Panel (NNAP) also participated in the Congressional Hearing that reviewed the US position with respect to nanotechnology in 2005, the NNAP main goal is to review the Federal nanotechnology research and development program. In this opportunity the NNAP delegate reported by the first time the necessity to consider studying the societal implications of nanotechnology. For the first time they suggested to allocate more research funding in studying environmental and health effects in each of the federal agencies members of the

NNI, but at the same time the NNAP recognized that NNI was already moving forward to identify, prioritize, and achieve these concerns, the research orientation to health and environment studies of nanotechnology was emphasized in the following piece of the NNCO presentation in the House of Representative:

"The NNI and NNCO are more organized on this front than when the PCAST first began its review of the NNI two years ago. Because, as many members of the Congress and this committee have rightly pointed out, addressing risks and societal concerns is so important, the NNAP placed special emphasis on this topic, and will continue to do so. In addition, communication with the various stakeholders, including the public, on these topics is an important element of the program. Therefore, we were pleased that the interagency group managing the NNI established a new subgroup to address the topic of public engagement."

This NNAP statement represented the first evidence of lobby inside the representative house to conduct a shift in the research orientation from a nanotechnology research agenda oriented to generation of new products to give more competitiveness to the industrial sector towards funding research that allow the scientific community study the potential negatives effects from nanotechnology. This situation was the start point of the nano debate among the two advocacy coalitions. On one side, pro-nano members that shared an optimist view respect to nanotechnology contributions to the economy and society, and on the other side the pro nano-regulation group that shared concerns respect to potential risk associated with this new technology advocating for a new regulation framework for nanotechnology and more federal invest in EHS research, in order to assure that these risks do not overcome the potential benefits showed by the rival coalition. For instance, in the discussion section of the hearing the Chairman Inglis made a question to one of the industry representative about his perception that the environmental issues has just linked with nanotechnology and what were his thoughts about the relation of these two concepts. The industry representative brought about the case of DuPont a US base transnational agrifood corporation that at that point was leading EHS research on the real risk. Meanwhile, others were concerned with respect to perceptual threats, that seem to be born from the ignorance rather than scientific evidences, but which can damage the commercialization of new products as much as real risks, he used the case of genetically modified organism in food in Europe to support his point of view.

6.4The Nano-debate on Risks versus Benefits

In November 2005, the Committee on Science of the House of Representatives hold the first hearing session on EHS aspects, which goal was to assess the current state of knowledge of nanotechnology EHS, and the research plans on the environmental and safety implications. This CHH was called “environmental and safety impacts of nanotechnology: what research is needed?” In this opportunity five witnesses were presented, two from the industry, one from NNI, and other two non-governmental organizations such as the Project on Emerging Nanotechnology a think tank of expert from the Wilson Center and the Environmental Defense Fund a NGO working in sustainable development stakes. This hearing brought consensus among the participants that the government has the responsibility to take action on bringing the required funding to assure that the nanotechnology R&D in the US has been doing correctly, it means giving attention to both benefits and potential risks. The chairman opened the session with the following statement:

"The need for more research on the environmental and safety aspects of nanotechnology is made amply clear by our non-governmental witnesses this morning, who speak in their written testimony with remarkable unity. Boy, that is refreshing to hear from this side. Their message is clear, and it must be heeded: if nanotechnology is to fulfill its enormous economic potential, then we have to invest more right now in understanding what problems the technology might cause."

This type of agreement among different coalition members in increasing support to EHS research has some nuances for each coalition. For instance, the representative of the Nanoscale Science Engineering and Technology Subcommittee (NSET) said that all the federal agencies involved on NNI were currently working proactively to achieve this challenge to fostering nanotechnology with equally strong consideration on EHS issues. But at the same time, he recognized a low risk to people and nanotechnology workers, with the following paragraph:

"Most nanotechnology-based products pose little chance for public exposure and therefore pose little risk to health or the environment. Manufacturers already minimize exposure to fine particles in the workplace"

Hence, the NNI representative testified that the EHS research was already investigated and he particularly diminishes the likelihood of risk associated to this emerging technology. This view is shared by industry people, who agreed with the idea of paying attention in EHS research, but they wanted to make the point of not giving that much attention in issues that had been proved to be safety. They called perceptual risk to the phenomena of overreacting with respect to potential risk that never become reality, but people are skeptic with respect to use them even if they prove to be harmless. They argued that this type of belief can act as a barrier for commercializing this type of technology, just as it happened with the choke on GMOs applied in Western Europe.

The Wilson center representative came to the witness with a quiet different argument respect to the role government must have in guarantee the safety of new technologies. At that point in time PEN carried out several focus groups across America assessing the public opinions and concerns with respect to nanotechnology, so then in the hearing the PEN representative wanted to share the views from people that tend to be under-represented. He started his testimony with a quote from one of these focus groups, in which one person said:

"I found it interesting that so many government agencies are potentially responsible for nanotechnology. With so many agencies, bureaucracy enters the process because everybody is fighting over who is responsible" He added, "*until something goes wrong. Then nobody wants the responsibility."*

So then the role that this type of organizations is shade light on the issue of preventing future unexpected consequences from the use of emerging technologies as nanotechnology and be the channel of communication among policy makers and the public in general on these topics. They believe that people have the right to rise questions in regards to potential risks, type of regulation framework placed to protect the environment and society. Because they have the right to be informed about the government initiatives with respect to nanotechnology. Organizations like the Wilson Center wanted to be involved in the nanotechnology debate to ensure that the government is promoting the good science under the best governance scenario.

With a similar position as the Wilson Center, the Environmental Defense Fund's scientist shared the enthusiasm about potential societal benefits offered by nanotechnology R&D, but at the same time, they claimed an urgent necessity the US government takes action to increase the research funding oriented to EHS issues, because an early understanding of the interaction of nanoparticles in the environment and human health is required to reduce potential risks. He compared the case of genetically modified organism (GMOs) research and development in agriculture which had a fast transfer to commercial applications in the agriculture sector, but it started to receive concerns by civil society representatives and consumers about potential risk that was not addressed on time provoking public criticisms, closed markets, and product bans. He thinks that the only way to come up with a future reality from a radical innovation in nanotechnology is through dealing on time with a strong risk assessment framework that guarantees safety.

Since 2006 the pro nano-regulation advocacy group started a more active campaign to demand federal agencies to make the regulation of new products that contain nanoparticles, several events occurred in the nanotechnology policy subsystem in 2006, these events are summarized in the following table:

Table 12: Advocacy Group Members' Participation on the US Nanotechnology Regulation Framework in 2006

Date	Event	Participants
May 2006	Pro nano-regulation coalition demanded FDA respond a legal petition on control products that contain nano under the Federal Food Drug and Cosmetic Act (FFDCA)	ICTA, Friend of the Earth, Greenpeace, ETC group, Clean Production Action, and the Center for Environmental Health
June 2006	Letter signed by 14 companies and organizations sent to the House and Senate Appropriations Committees, emphasizing the critical importance this year of providing adequate funding for the environmental, health, and safety (EHS)	Arkema, Inc. , Air Products & Chemicals, Inc. , Altair Nanotechnologies Inc. , American Chemistry Council , DuPont, Basf, Bayer, Degussa, Dow, the Union of concern scientists
July 2006	Report proposing a research strategy for assessing risks of nanotechnology. The report criticized the lack of federal coordination to set research priorities, distribute tasks among the agencies, and ensure enough funding.	The Wilson Center's Project on Emerging Nanotechnologies
August 2006	FDA Noticed of Public Meeting Request for Comments Regulated Products Containing Nanotechnology Materials	FDA officials
August 2006	FDA announced the formation of an internal Nanotechnology Task Force	FDA agency managers and scientific staff
September 2006	109th Congress hearing: research on environmental and safety impacts of nanotechnology: what are the federal agencies doing?	Nanotechnology, Environmental, and Health Implications Working Group (NEHI) commissioner, NSF and EPA members, The Wilson Center, and the Lux Research Inc representative.
October 2006	FDA Public meeting and soliciting public comment	Center for Food Safety, ICTA, NanoTox Inc, Intertox, BASF Corporation,

October 2006	REPORT: Regulating the Products of Nanotechnology: Does FDA Have the Tools It Needs?	The Wilson Center's Project on Emerging Nanotechnologies
November 2006	FDA provided an interim response to the legal petition, informing them that FDA was unable to reach a decision, because the petition raised complex issues requiring extensive review and analysis.	FDA officials

During 2006 at least nine events related to the institutional framework of nanotechnology in the US were observed. This new stage in the nanotechnology policy process was influenced by the active participation of the pro nano-regulation advocacy group, which started to take collective actions to strengthen the US institutional framework that governed nanotechnology. They complained that after six year of the national initiative creation, and millions federal dollars invested in nanotechnology R&D with an emphasis on generation of new market products that allow the improvement of the US industry economic performance, very few attention was oriented to study the potential risk associated to nanotechnology. In 2006 it gained momentum to open the debate respect to the necessity of investing more federal funding in EHS research. This idea of unfunded EHS research was leaded by environmental NGOs members of the pro nano-regulation group, although this idea was shared among all actors of the system, even industry representatives that testified in congress hearings the aim of supporting this goal. This general consensus allowed and slight increase from 3% to 5% of the total NNI budget oriented to EHS research.

In spite of the pro nano-regulation coalition achieved their goal to raise the attention on the necessity to invest more in EHS, they still believe that 5% of funding oriented to study the risk of nanotechnology is insufficient, they expect at least 10% of the annual NNI funding goes to this matters. Moreover, in 2007 the U.S. Representative for Washington Brian Baird Chairman of the 110th Congressional Hearing on "EHS research current status" opened the hearing with the following statement:

"So the question before us today is not whether EHS research is important nor whether the NNI should fund research on environmental and health risks. The question is how effectively is the NNI carrying out the planning and implementation of the EHS research component of the interagency program[18]*."*

Hence, in the following years the focus of the debate changed from emphasizing the importance of EHS research toward review if the institutional framework was capable to effectively carry on an effective work in assuring the harmless use of nanotechnology (see Table 13). Several criticisms arise from pro nano-regulation advocates and also some legislators that recognized an inexplicable delay from NNI commissioners to come up with a strategy plan to conduct the required EHS research.

In February 2008, 18 months later than expected the NNI releases the Strategy for Nanotechnology-Related Environmental, Health, and Safety Research report. In March 2008 the National Research Council organized a Workshop with researchers, industry representative and NGOs, to review NNI EHS research strategy. The main conclusion from this workshop was to hint the NNI report as a very incomplete one, because it did not consider the essential element of a nano-risk research strategy. Moreover, they

[18] Congressional Hearing on Environmental and Safety Impacts of Nanotechnology last visited on October 18 at http://archives.democrats.science.house.gov/publications/OpeningStatement.aspx?OSID=2270

believe that this report did not contain clear set of goals, plan of action, and it failed in allocating required funding to achieve the EHS research goals. The workshop final conclusions gave a strong critics expressed in the following paragraph of the report "There is no attempt to show how existing research will lead to answers to critical questions that the federal government, the research community, and other stakeholders are grappling with.[19]"

The hard set of critics that the NNI EHS strategy 2008 report received from nanotechnology stakeholders obliged the NNI to prepare a new draft that consider the comments and critics, which was released two years later in December 2010, this time the NNI offered a time for receiving feedback from public comments, more than 24 were received and well integrated to the final report in October 2011 as Andrew Maynard professor at University of Michigan Risk Science Center pointed out in a blog 2020 science[20]. This last version replaced the previous 2008 ones and finally reached the nanotechnology's stakeholders wishes of having a clear strategy plan for EHS, but it becomes a reality with more than five years of delay.

Table 13: Advocacy Group Members' Participation on the US Nanotechnology Regulation Framework Period 2007-2012

Date	Events	Participants
July 2007	FDA Nanotechnology Task report with recommendations for regulatory policy to address regulatory challenges that may be presented by products that use	FDA Task Force Committee

[19]National Research Council Workshop report, last visited October 18 2012 available at: http://www.nap.edu/openbook.php?record_id=12559&page=105#p20016df69970105001
[20]Last visited October 20 2012 available at:http://2020science.org/2011/10/15/us-national-nanotechnology-initiative-to-release-latest-environmental-health-and-safety-ressearch-strategy-oct-20/

	nanotechnology.	
October 2007	110th CHH, Testimony to the House Subcommittee on Research and Science Education: Hearing on Research on Environmental and Safety Impacts of Nanotechnology. Current Status of Planning and Implementation under the National Nanotechnology Initiative	NNI representative, The Wilson Center's PEN, Environmental Defense Fund (EDF), American Chemistry Council (ACC) and PPG Industries, Inc.
February 2008	NNI Strategy for Nanotechnology-Related Environmental, Health, and Safety Research	NNI
March 2008	National Research Council Workshop for Review NNI Strategy for Nano -Related Environmental, Health, and Safety Research	NRC, researchers, policy experts from the European Commission, manufacturing industry, NGOs, and the Insurance sector.
March 2008	Hearings of the Subcommittee on Research & Science Education: The Transfer of National Nanotechnology Initiative Research Outcomes for Commercial and Public benefits	Oregon Nanoscience and Microtechnologies Institute (ONAMI), University of Massachusetts, Nanoelectronics, IBM, Nanosphere, Inc. & NanoBusiness Alliance, and Molecular Imprints, Inc
April 2008	Testimony to the House Subcommittee on science, technology, and Innovation: national nanotechnology initiative: charting the course for reauthorization.	University of South Carolina, Nanobiosym Diagnostics Inc, Caltech, Lux Research Inc, PEN, Natural Resources and Environment,U.S. Government Accountability Office, and OSTP.
July 2008	FDA Public meeting and request for comments: Consideration of FDA-Regulated Products that May Contain Nanoscale Materials	ICTA, IFT, PEN, Center for Food Safety, FoE, Center for the Study of Responsive Law (CSRL), Consumer Union
September 2008	National Nanotechnology Initiative Amendments Act of 2008 (adjusted some NNI priorities like more focus on environmental and safety research)	The U.S. House of Representatives Science and Technology Committee
April 2011	112th CHH: Nanotechnology: Oversight of the National Nanotechnology Initiative and Priorities for the Future	National Nanotechnology Coordination Office, Semiconductor Research Corporation and

		Semiconductor Industry Alliance, Liquidia Technologies, Rice University, Nanosphere Inc.
June 2011	EPA Proposes Policy on Nanoscale Materials in Pesticide Products. Public comments	Several Anonymous public comment, individual comments, mass comments from FoE, Center for Food Safety (1982), Food and Water Watch (2438), ICTA, etc.
June 2011	FDA draft guidance "Considering Whether an FDA-Regulated Product Involves the Application of Nanotechnology"	38 comments, 25 from industry and 4 from NGOs
August 2011	FDA published "Advancing Regulatory Science at FDA Strategic Plan," which encompasses nanotechnology."	FDA
October 2011	NNI environmental , health, and safety research strategy this one replace the 2008 report	NNI
April 2012	FDA response to ICTA petition 2006: FDA determined that it does not provide sufficient data and information to persuade FDA to take the specific actions they requested.	FDA

6.5 The Battle for Regulating Nanotechnology

It took more than five years to come up with a national strategy plan to study the environment, health, and safety issues related to nanotechnology, the establishment of a new regulation, in the short run, that frame the rule of the game by which nanotechnology is conducted in the different stages, such as research, development, production, commercialization and disposal seems unlikely. Another example of the slowness in adaptation of the institutional framework is given by the long six years that took FDA provide with an official response to the legal petition placed by pro nano-regulation advocacy group to control products that contain nano under the Federal Food Drug and

Cosmetic Act. Which final response was to determine that it does not provide with sufficient data and information to persuade FDA to take the specific actions on the social organizations requested in year 2006.

Meanwhile, in June 2011 the FDA released the draft guidance for industry called "Considering Whether an FDA-Regulated Product Involves the Application of Nanotechnology". This document was in word of FDA the first step toward providing regulatory clarity on FDA's approach to nanotechnology. But this guidance was received with partial enthusiasm from pro nano-regulation advocacy group, because it did not establish any legal enforcement responsibility to the industry. Instead, it pretended to show the FDA's position respect to nanotechnology regulation and gave some recommendations to the industry. But this guidance also received critics by the pro-nano coalition members, particularly from industry representatives that disagree with the FDA suggestion of modifying the formal definition of nanotechnology that consider the size of nanoparticles as a parameter to define nanotechnology, from the original size range of approximately1-100 nanometers up to one micrometer (1000 nm) in external dimensions. The recently release of the FDA's guidance has been enough motivation to both coalitions to movilize their members and takes new actions towards trying to influence the FDA position in relation to the redefinition of nanotechnology.

So, why this important for each coalition the debate respect to definition of what are nanotechnology products. On one side, The pro nano-regulation coalition has advocated since the beginning of the nano-debate to increase the upper level limit of 100 nanometers up to at least 300 nm, because they believe that many industries in order to avoid new pre-market test for products that contain nanoparticles could just increase above 100 nanometers the size of the nanoparticles used to skip from new regulations. On the other side, pro-nano advocacy group has claimed that is not necessary to enlarge the upper limit of 100 nanometers in the nanotechnology definition, because they believe that the real new properties obtained from nanotechnology only are present at a size lower than 50 nm. Table 14 show some pieces of a total of 28 comments received by the FDA public comment on the Draft Guidance for Industry Considering Whether an FDA-Regulated Product Involves the Application of Nanotechnology[21]

Table 14: Public Comments on FDA's Draft Guidance

Pro-Nano Advocacy Group	Pro Nano-regulation Advocacy Group
EWG: supports FDA's proposal to consider size-dependent properties of particles larger than 100 nm, a measure frequently used as an outer parameter for identifying nanomaterials.	**Society of Chemical Manufacturers and Affiliates (SOCMA):** While the Coalition acknowledges the absence of a clear upper limit bright line, there is a preponderance of evidence that shows the most commonly accepted definition is a size range of between 1 and 100 nm in at least one dimension.
Consumer Union: We also applaud FDA for recognizing that these unique properties are also a concern for materials having structures in the range of 100 to 1,000 nm and that the safety implications of engineering features in this size range also warrant consideration.	**Nanophases Technologies Corp:** The size definition is extremely vague (respect to 1-1000 nm) because primary particles are really between 1-100 nm.
Food and Water Watch: We urge FDA to quickly define the size range it plans to use in determining whether a product is composed of nanomaterials. And we urge FDA to use 1,000 nm as the upper limit of that range.	**American Chemistry Council**: The Panel appreciates that FDA states clearly in the draft guidance that these dimensional considerations (1-1000 nm) are not parts of a regulatory definition.
	Society of the Plastic Industry (SPI): agrees with the range of 1 nm to 100 nm as it is consistent with consensus reflected by the U.S. NNI.
	Biotechnology Industry Organization (BIO): "Nanosized material" does not Imply Potential Harm or Risk. We do not believe that the one

[21]Last visite don November 20 2012 at http://www.regulations.gov/#!documentDetail;D=FDA-2010-D-0530-0002

	micrometer size limit is helpful in addressing FDA's apparent concern that materials outside the nanoscale range may display nanoscale properties or phenomena. Instead, we suggest it would be more straightforward to address agglomerates or aggregates by keeping the upper limit of 100 nm
	Enzyme Technical Association ETA: agrees that enzymes, which are proteins, currently do not fall into the scope of nanotechnology. To avoid confusion in the future between nanotechnology and biotechnology and because enzymes can be products of protein modification, ETA recommends adding the word "enzymes" to the last sentence in III.B.1

Source: Docket ID: FDA-2010-D-0530 last visited November 12 2012 at

http://www.regulations.gov/#!searchResults;rpp=25;po=0;s=FDA-2010-D-0530

Most of the public comments received by FDA came from industry representatives (24) and only few comments from pro nano-regulation advocacy groups. In general all comments from both coalitions appreciated the FDA effort to communicate its views and with that give more transparency with respect to nanotechnology activities. Nevertheless, the main discussion was centered in the attempt of FDA to give a more broad definition of nanotechnology, which made some trouble to several industry representatives who showed their disagreement with the idea of enlarging the size up to 1 micrometer in the definition of nano-devices. This industry attitude to discharge the proposed new nano-definition makes sense with arguments presented in the literature review section of this thesis, which mentioned that in general the industry has a preference to avoid the generation of new nanotechnology regulations. Or in the case a new regulation is settle, they wish their nano-products remain outside of the formal definition in order to avoid future regulations on aspect such as labeling that could affect the commercialization of their products.

Interestingly, very few feedbacks were received from the main actors of the pro nano-regulation groups who always take any opportunity to engage in the policy debate. The few pro nano-regulation members that reply the FDA comments with a strongly agree with regards the new FDA definition that considered to increase the upper level up to 1 micrometer. This scarce participation can be explained by two factors. The first one is related to a general discouraging among coalition members that feel that the battle of advocating for more regulation is lost. Their capacity to influence policy makers to establish a real regulation framework has been minimal. Moreover, they note painfully that the federal agency that should be the responsible for regulating nanoproducts alternatively offer recommendations which have not any legal enforcement that allow the control of nano products that are being commercialized and consumed by the US population.

The second factor that in part can explain the limited actions of the pro nano-regulation coalition was obtained from one of my interviews with a member of this coalition, who mentioned that they thought the FDA statement was pretty good, particularly with respect to in raise the upper level of size definition of nanoparticles up to 1 micrometer, which idea has been in the core of the coalition, this increase in size definition is even better from what they has been advocated (300 nm). Because they see many nanoparticles used in food application that currently is over 100 nanometers in size can avoid the all concept of nanotechnology. So then, they do not see much pressure in the short run to influence through comments of mass campaigns with their members.

6.6 Conclusions

The nanotechnology institutional framework in the US has remained with no variations since the start of the nanotechnology initiative. Pro nano-regulation claim for the establishment of a set of regulations that can reduce their concerns with respect to potential risks associated with nanotechnology. But after more than a decade, they only have gained some few small battles in relation to influence policy makers in this respect. For instance, the increase in research funding oriented to nanotechnology EHS issues has been one of their successes, but partially because still they advocate for a higher amount of federal funding goes directly to EHS research.

The ACF framework also recognizes a source of policy change to external events of the subsystem. Such as change in socioeconomic conditions, change in public opinion, and change in systemic governing coalitions. In the case of nanotechnology debate only could be affected by the last one, due to change in the political context with the election of Barack Obama as the new democratic President of the United States in 2009. In spite of this change in political contexts, no differences were observed with respect to the composition of the congressional hearing witnesses later on April 2011. In this opportunity again the congressional hearing was mainly integrated by industry representatives and researchers (see Table 13).

Pro-nano advocacy group has shown to be success in influencing policy makers particularly in the US Congress, where in all five CHH this coalition was represented by more than one member, such as university researchers or/and industry representatives, who testify stressing their points on showing the economic and social benefits from investing public money in nanotechnology research. On the contrary, the participation of pro nano-regulation members was only considered in few congressional hearing when the focused on the hearing was in EHS issues. Moreover, the Environmental Defense Fund was the only social organization that was invited to these hearing, leaving the other actives ones outside of these hearings. NRDC, Friend of the Earth, ICTA, Food and Water watch, and Center for Food Safety have focused their efforts in influencing two federal agencies that are responsible of the regulatory framework FDA and EPA. These social organizations that also are members of the pro nano-regulation coalition participated actively in the public hearing offered by these two agencies. They used several resources to achieve their goals, such as presenting their arguments in public hearing, sending written comments, and also mobilizing their troops through organizing public campaigns to collect mass comments from followers and citizens that share their beliefs and concerns with respect to nanotechnology potential risks.

Sustainability has not clearly emerged as a concept of discussion from the public hearing and comments. The coalition goal of increasing the current research funding in EHS issues has only been partially related to sustainable issues. But interestingly, most of the active members of the pro nano-regulation coalition remain passive in this kind of activities, especially from those Congressional Hearings in nanotechnology where the witnesses were generally part of the pro-nano advocacy coalition.

Finally, some other actors of the agrifood sector who I expected they have an active role in the nanotechnology debate were absent. For instance, farmers' organizations that have been presented in other debates such as GMOs, in this opportunity remain silent. The lack of participation of these traditional farming organizations in the nanotechnology institutional debates and forums, brings about minor research focus toward crop production.

CHAPTER 7.

CONCLUSIONS AND POLICY IMPLICATIONS

7.1 Introduction

In the previous chapters of this dissertation I analyzed the concepts required to articulate the theoretical framework considered in my thesis. Agrifood sector, nanotechnology, public research agenda, advocacy coalitions, and sustainability were among the most important concepts utilized to give response to my research questions. The Sectoral System of Innovation utilized in this dissertation that consider the technology, the actors and their interactions, and the institutions as the three building blocks by which each sector utilizes scientific knowledge to promote innovations. The dissertation has examined these three building blocks. First, in Chapter 4 I studied how the public nanotechnology research agenda has been established and evolved during the last decade in the US agrifood sector in term of research orientation toward sustainable development. Second, in Chapter 5 I studied the actor interaction in advocacy coalitions, and the type of beliefs, arguments, and resources they utilized to achieve the coalition goals. Finally, in Chapter 6 I studied how these advocacy groups put in practices their influential activities in policy making arena to try to influence the research agenda. In the following section I will provide the main observations and findings in each of these three relevant aspects of the US agrifood nanotechnology sector.

7.2 General Observations and Findings

The dissertation focused on the study of the Public nanotechnology research agenda in the US. The main research goal of the dissertation has been to detect the presence of advocacy coalitions groups that work together to influence the research agenda. I started my dissertation with a general hypothesis that expected to find at least two rivals advocacy groups. On one side, a pro-nano group composed mainly by researchers, federal agency managers, and industry representatives who share the believe that nanotechnology research can revolutionize the way food is produced, I assumed that they wanted to increase the federal funding to support their research to improve crop productivity and produce better quality food. On the other side, I expected to find an anti-nanotechnology group that is against the use of nanotechnology research and development applied to the food production. I hypothesized that this anti-nano coalition should be composed by farmer organizations, environmental NGOs, workers and consumer unions, and other alternative agriculture production systems, such as organic farming. (See figure 3 for details of the theoretical framework).

Three data sources I used to give response to my research questions, nano-publications, semi-structured interviews, and literature review of official documents of the US nanotechnology system were very useful to study the US agrifood nanotechnology sector, because they complemented each other well to reduce some individual limitations that each of them present. For instance, the bibliometric analysis of research publications gives complete information about the type of research and the researchers that participate in the agrifood nano sector, but this database does not consider other actors of the policy subsystems, such as federal agencies and social organizations. These other actors can be obtained from the literature review and through snowball effect of asking in my interviews about other key actors that did not showed up in my previous searching strategies in my dataset.

After concluded my research I found two coalitions, the first one pro-nano, and another coalition different to the against nanotechnology coalition which was not the one that I expected. Moreover, among the actors that I had expected to find in my research I could not find non-trivial type of collaborative actions toward banned the nanotechnology development among farmer organizations, organic farming organizations, and NGOs. Even though, some of these organizations have been working in some ways related to the agrifood nanotechnology research agenda, they have shown differentiated degrees of participation. For instance, I found only one farmer organization, the Soya Bean Producer Association which is currently financially supporting nanotechnology research in order to improve yield and crop quality in conjunction with university researchers. But in general, farmer organizations have remained aside of the research agenda debate.

Three research questions framed my research inquires. The first question was to assess: How much attention does sustainability receive in research on nanotechnology applications in the US agrifood sector and how has it changed over time? Utilizing a bibliometric analysis of the scientific publications related to agrifood nanotechnology during years 2000-2010. I found that the nanotechnology research agenda has grown fast during the period of analysis. Nevertheless, very few US scientific publications were directly related to sustainability issues, although during the second part of the last decade, nanotechnology EHS research publications related to agrifood sector grew higher than the general world publications related to EHS. This important finding show that the influence of pro-EHS research subgroup and the pro nano-regulation groups succeeded in defend the position that more EHS research is required in the US. Their influence not only increase the public research funding oriented to this matter, but also it produce an increase in the number of publications related to study EHS issues in the agrifood sector.

The Sustainability concept articulated in this dissertation was taken from the UN Commission on Sustainable Development, and the sustainable goals articulated by the National Research Council Committee on twenty-first agriculture system. This definition considers four dimensional sustainable goals with a total of 26 sustainable indicators which were evaluated in the bibliometric analysis of agrifood nanotechnology publications (period 2000-2010). The main finding from this analysis was that scientific articles not necessarily address the four sustainable goals.

After reading each abstract with special attention to the four sustainable goals, it is possible to determine that indirectly most of them achieve at least one of the four dimensions, this is the case of articles that studied nanotechnology applied to soil and water systems. The dimension less covered by the dataset was the number 3: “Sustain the economic viability of agriculture and food production”, because most of the research papers are focused on the technical aspects of the technology or the problem that intend to solves, but they do not necessarily fulfill the principal farmers’ aims. Additionally, they do not discuss the way these new technology will be commercialized. There are some doubts from pro nano-regulation coalition members that believe that as well as GMOs, all benefits will be only obtained by the traditional agrifood transnational corporations and will keep farmers captured by their business models.

In US research agenda stand articles that studies nanoparticles interaction in water, soils, and environmental processing to reduce current negative effects from agriculture practices, such as techniques of soil remediation. The other relevant topic of research in the US agrifood sector has been topics related to food safety like the use of nanosensors to detect food pathogens. These applications of nanotechnology in the agrifood sector can certainly contribute to sustainable development, but it will depend on the type of nano-device that the sensors are made. Because, so far no conclusive scientific evidences has eliminated the concerns raised by pro nano-regulation about potential risks, which mention engineered nanoparticles (carbon nanotube and metallic nanoparticles) as source of concern with respect to potential harms to the environment, human health, and worker safety.

The indirect relationship between nanotechnology and sustainability is observed in the food safety research that seeks to develop faster, cheaper, and easy to use pathogen detection test that can contribute to the improvement of the social and economic dimensions of sustainability concept, but it could harm the environmental dimension if this use not biodegradable nano-device which can generate toxicity when they are release to the environment. One contribution to this concern can be obtained from the shift in the agrifood nanotechnology research agenda towards the use of natural-base biodegradable nanoparticles from cereal crops and wood-cellulose. The natural nanoparticles promise to eliminate the risk concern and contribute directly to sustainable development. Moreover, through the use of natural raw materials this type of technology may enhance the life quality and economic viability of rural population.

The second research sub question of this dissertation was to know: What actors are involved in the US agrifood nanotechnology research agenda and do they form advocacy coalitions? I conducted 24 semi-structured interviews with key actors of the agrifood sector. I used the theoretical framework developed by Sabatier et al. Advocacy Coalition Framework, which consider the sharing of core beliefs among coalition members as the incentive to join in coalitions in a determined policy subsystem. In my dissertation I considered the US agrifood nanotechnology as the policy subsystem subject of analysis. The pro-nano advocacy group was composed by university researchers, federal agencies managers, and industry representatives. They shared the belief that nanotechnology offer huge opportunities to be applied in the agrifood sector, so then they try to influence policy makers about investing more federal funding in research and development in order to achieve higher benefits for the industry and the society in general. The rival advocacy group started to work later the first years of the NNI creation, formed mainly by environmental NGOs, workers unions, and some consumer organizations, which showed concerns with respect to potential risks associated with using nanotechnology in the agrifood sector. This advocacy group proved to be in disadvantage in terms of availability of resources, in particular financial resources and time to conduct effectively a campaign to lobbying members of the US Congress and other federal officials to request higher amount of federal funding oriented to research that seek to understand the nanoparticles behavior in the environment, health and safety issues, and also more risk related research. Even though more active members of this coalition should prefer to conduct more aggressive campaigns in order to put in place a new federal regulation framework to nanotechnology R&D and new nanoproducts, they share a feeling of frustration, because after more than six years of fighting for set a new nano-regulation in the US, the system has remained unregulated with new nano-products released everyday into the market without testing them to guarantee their safety interaction with people and the environment.

This feeling of frustration with respect to the progress in the nanotechnology institutional framework can explain the lower level of activities detected in this study in the pro nano-regulation coalition during the last years, transforming the pro nano-regulation in a minority coalition, which after several years of coalition actions to influence the institutional framework of nanotechnology in the US, they decided to shift their strategy toward a more feasible goal of increasing the federal funding sources oriented to environment, health and safety research (EHS). The status quo in the policy process has been explained by the no occurrences of internal shocks that can allow a change in the policy subsystem, as well as the no occurrence of any external shock, such as solid scientific evidence that show the risks of nanotechnology applications in the agrifood sector. Meanwhile the pro-nano regulation coalition is waiting the moment to intensify their actions after the occurrence of this external shock, for example, if someone get sick or died by manipulating nanoparticles. This type of negative events can give notoriety to the problem, gain followers, and new members willing to invest more time and financial resources to fight over nanotechnology regulation.

The third research question of the dissertation was designed to know about: What role does the advocacy coalitions play in the shaping of the agrifood nanotechnology research agenda in the US agrifood sector? A study of congressional hearings on nanotechnology issues, complemented with a revision of official documents and reports during the last ten years allowed me to analyze the role that each coalition has played in influencing the establishment and further transformations on the US agrifood nanotechnology research agenda. The analysis found an evident supremacy of the pro-nano advocacy group in influencing policy makers, which along the time participated in almost every workshops and public hearings offered by congress and federal agencies to speak about the tremendous potential benefits that nanotechnology can bring to the sector, and emphasize the necessity to invest more in applied research to maintain the US leading position in nanotechnology research &development related to closer international competitors. However, when the pro nano-regulation raised the awareness about potential risks associated with nanotechnology, they agree in the necessity to increase the amount invested in EHS but in a reasonable quantity that not hurt the current scarce federal funding oriented to agrifood nanotechnology.

These three sub questions assemble my main research question that guided my thesis, which was to know the following: Did the formation of advocacy coalitions affect the attention paid to sustainability issues in the agrifood research agenda? In chapter 4 I studied the US nanotechnology research agenda and how it has changed over time, showing three clear paths. The first one is that the environmental processing research as always occupied a predominant place in term of number of agrifood publications. Second, the research agenda has been dominated by research in food safety aspects with the research and development of nano-biosensors as the primary nano device used to solve toxicological problems associated with food production and consumption. These two research topics can contribute to sustainable development, reducing contaminants in soil and waters streams and offering good quality food respectively. Finally, the third path observed from the evolution in the agrifood nanotechnology research agenda is the rise in EHS publications. This has been a result from increasing attentions given to this topics not only by the pro nano-regulation advocacy group, but also by members of the sub group called pro-EHS research belonging to the rival pro-nano advocacy coalition.

The rise in federal funding for EHS research is one connection point between the two rival coalitions. Proponents of this goal are mainly researchers in toxicology and environmental science, social scientists, and federal agency managers from EPA, NSF, and USDA who administrate EHS funding programs and would like to have more federal financial support to conduct this research. In spite of their different way of thinking about nanotechnology, they share the same believe of unfunded EHS research in the US, as well as similar arguments to support the increase on federal funding in EHS issues are similar, so far they utilize two different strategies to achieve their group goals, approaching to the problem from different angles. On one side, pro-EHS group follows formal channel of communications to express their desire of seeing more EHS research financed by the government. They communicate their thoughts and expectations in workshops and conferences where they regularly participate. On the other side, pro nano-regulation has few opportunities to participate in those formal channels, so they use their more valuable resources, skillful policy analysts that communicate to the public in general through the utilization of mass media sources, such as blogging and reports shared with their followers and the public. But interestingly they have not been aware of the presences of potential allies in the rival coalition, who are in a better influential position to influence the decisions by governmental authorities to increase EHS research at least up to 10%.

There is another incipient connection point between the rival coalitions if this becomes a reality could contribute directly to the shift of the agrifood nanotechnology research agenda towards sustainability. But so far no type of communication or joint activities between the EHS-subgroup and the pro nano-regulation group were observed.

If the Bio-base nanoparticles advocacy subgroup composed by researchers, who have used natural-base nanoparticles from agriculture crops and wood sources demonstrate the practical applications obtained from using their biodegradable nanomaterials without hurting the environment, and human health, these new natural-base nanoparticles could replace the use of controversial metal and carbon nanotubes as nanodevices which are in the center of the nano-risk debate. Hence, new biodegradable natural base nanoparticles can both contribute to reduce risk and concerns respect to using nanotechnology in food, and supply a sustainable agrifood system.

7.3 Theory Implications

The study of the US nanotechnology research agenda in the agrifood sector from the perspective of two theoretical frameworks, the sectoral system of innovation and the advocacy coalition frameworks, both contributed to give response to my research inquiry. So after concluding my research I would like to make a reflexive analysis on both theoretical frameworks, with the aim of trying to contribute to the development of each framework with the learning process obtained during this dissertation work.

Malerba the author of the SSI focuses attention on studying the innovation process, which varies depending on the sector where the innovation happens. Each sector shares basic knowledge and a set of activities to produce a particular product. The actors in the sector are clearly identified: government, industry, and research organizations that interact using technology to produce innovation process in the system. The SSI assumes full information about the technologies, actors, and institutions. Then, the study of these three building blocks generates the innovation process that enhances the sector competitiveness. Nevertheless, the agrifood nanotechnology sector compared with other sectors previously analyzed by the SSI framework shows a lack of information and transparency, mainly because of the presence of a pro nano-regulation coalition that has raised their concerns about potential negatives effects from using or eating food with nanoparticles. This worry also has affected the food industry, which seems not to have enough incentive to participate in public debate with respect to nanotechnology research and development. As a consequence of this there is a reduced flow of information in the system, . The reduced information with respect to what type of research and the potential new products are being developed by agrifood industry, such as chemical and food processing industries, affect the learning process that SSI distinguished that can occur when there are more information and knowledge sharing among the system actors. This make the agrifood sector a more complex system in regards to evaluate the role that play additional actors besides the government, industry, and researchers, such as NGOs, worker unions, and consumer organizations, which was not primarily consider by SSI. This makes the Advocacy Coalition Framework a contribution into the Sectoral System Innovation framework. The ACF framework sheds light on the agrifood system because it provides better understanding of actors and their interactions.

A manner to improve the analysis of those characteristics that affect the learning process that take place inside the sectoral system is by using the Advocacy Coalition Framework. ACF was established by Paul Sabatier to study the policy process inside of what he called the policy subsystem, in which policy actors join in coalition's base on sharing similar set of beliefs. Meanwhile the SSI was very useful to delimit the variables involved in the nanotechnology research agenda, the ACF contributed to take a deeper analysis of the actors involved in the policy process. This theoretical framework not only consider those actors that are directed related to the technology as researchers, companies, and government, but also open the system towards other social actors that want to engage in the policy discussion about what they expect from the research and development of emerging technologies, and study what actions these actors carry on basis their beliefs.

Sabatier attempted to explain policy change within a policy subsystem in a relative long period of time, more than a decade or so. Nevertheless, in this study I consider a shorter period of analysis, in which two rival coalitions are actively participating in the nano-debate in the US, the pro-nano coalition is working since 2002, and the pro nano-regulation coalition since 2005. In my analysis of these coalitions I found that coalition's members (particularly those from the nano-regulation coalition)engaged in several other policy subsystems, such as GMOs, social justice, Organic farming, synthetic biology, etc. So the composition of coalitions is more dynamic of what Sabatier proposed. For example, some of the environmental NGOs policy analysts that lead the pro nano-regulation coalition, they also are leading other coalitions such as the GMOs, and when something remarkable situation happen inside the policy subsystem they articulate the actions to follow and call other members, who have remained more passive to join in the new actions. While, no new internal or external shocks occurs, they remain more quiescent focusing their scarce resources in tracking the scientific development and new discoveries that could affect or support their claims. Therefore, I propose that ACF should put more close attention on the composition of coalitions and the dynamics that occur among coalitions from different policy subsystems. Furthermore, ACF can also learn from SSI, with respect to delimiting the analysis to a determined sector, which has its own characteristics, in which the actors involved remain more stable over time. For example, the agrifood sector studied in this dissertation, has been the frame for several policy changes over the last century in the US under a stable institutional framework, with the participation of different coalitions that have took actions in each policy subsystem. Most of the same actors (researchers, farmers, companies, and NGOs) have engaged many times in those coalitions along the time. The delimitation of the system in sectors can bring valuable information about the actors, their beliefs, resources, and coordination that were put in place previously. In the case of agrifood nanotechnology policy subsystem I think that there are more similarities with previous coalitions of what we tend to think.

The SSI and ACF are both theoretical frameworks that are being applied for several policy scholars independently one of each other. This research attempted to use them together to better explain the interaction of actors of a system with imperfect information, as the agrifood nanotechnology sector. The SSI was useful to delimit the system in which nanotechnology research agenda is taking place. But it seems less effective to use this framework in studying technologies that are in early stage of development, which is the case of nanotechnology, because the composition of actors tends to change rapidly when the innovation is becoming a reality that it is transformed into a product or process commercialized in the market. Hence, the complementary use of ACF helped to solve in part this problem. Because ACF recognize policy actors that engage in the policy debate since early stage, it contributes to facilitate the analysis of actor’s influence in the policy process and the type of coordination within coalitions.

7.4 Policy Implications

In this section I attempt to give a practical description of what lessons can be taken from this dissertation research in relation to the implementation and development of a research agenda in the agrifood sector. For sure each sector and country has its own particularities that make them unique, but the study of the US agrifood nanotechnology public research agenda can be useful to take some learning from it to be shared with other policy actors that day to day are implementing research agendas in different sectors.

The public research agenda in the agrifood sector has played a relevant role since the independence of United States, because of the importance of the sector in the US economy. Public research agenda started with the establishment of agriculture institutions such as the USDA which has promoted mechanization and irrigation systems, plant breeding, hybrid seeds, fertilization, pest control, and the uses of GMOs in crop production. The results of those actions have been varied in terms of success. In general, these technological innovations have brought more productivity and availability of quality food, but at the same time, some of them have produced unexpected consequences, such as, toxicity, pollution, lost in biodiversity, etc. In the case of GMOs emerged as a scientific field that promises to benefit the sector, workers, and the society arose voices requesting for more studies that evaluate all potential consequences that included not only benefits but also potential negative effects. In the US context seems that some voices are well represented such as researchers and industry representatives that aim for more support to nanotechnology. Nevertheless, farmers have been systematically left outside of the policy process by which the research directions are discussed. I did not find any evidence during my research that these relevant actors were included in one of the several workshops, roadmaps, reports, and public hearings that discussed nanotechnology research in the agrifood sector during the last decade. Furthermore, the USDA agency which is the federal agency that is directed involved with farmers have not consider them in its nanotechnology strategy plan discussions. Even when the debates are about new technologies, farmers are not part of the stakeholders participants invited to present their concerns and ideas with respect to what new technologies, as should be required to make a better performance in the agrifood sector. But later, when the emerging technology is available in the market, farmers are the first ones in being involved with the technology, in the food production process, commercialization and consumption. So that, farmers are the key actors in accepting or rejecting these new technologies, being in that way the most relevant actors in relation to technology adoption. Hence, farmers are who determine the success or failure of new technologies as nanotechnology in a long term. If the technology is adopted by them, the public investment will be paid off. One explanation to the lack of participation of farmers in the nano-debate could be that nanotechnology applications in the agrifood sector still is in early stage of research, no new agrifood products have been commercialized, so then we should expect to see farmer as technology users involved in the debate when they are exposed to the technology diffusion. But certainly, the role that farmers play in the US agrifood nanotechnology research agenda should be studied with more detail in further research.

When the rest of stakeholders discuss about what type of scientific research area should receive more federal funding, it appears that no one asks farmers what type of problems they encounter in crop production, or which ones should be addressed first to achieve the government goals of producing more food, cheaper, and in a more sustainable way.

Another aspect in regards to policy implication from my research that is relevant to be considered for further studies is about the regulatory policy. In my research I found that each of the two advocacy groups plays a key role in trying to influence the nanotechnology institutional framework in the US. Both coalitions have plenty of skillful members, but none of them are explicitly against the technology, rather than these knowledgeable people from different coalitions can contribute to develop a more optimal nanotechnology regulatory framework that might consider the views and useful expectation to the all society, reducing potential negative cost to the environment and humankind.

7.5 Conclusions

Concluding, the US agrifood system is facing new challenges with respect to growing population, lack of natural resources, and nutritional problems that need to be addressed by the establishment of efficient public policies oriented to find solutions to these paradigmatic problems. Nanotechnology comes into sight as the most promising scientific response to those problems that I have mentioned along this dissertation. The US agrifood nanotechnology subsystem has all the necessary ingredients, such as an excellent scientific community, solid institutions, competitive food industry, and social participation among others to achieve these public goals. However, the final success to reach a more sustainable development that guarantee the enough resources for the future generations will depend on how the system integrates the vision and ideas from the entirely system actors.

APPENDIX A.

Case Study Protocol

I Theoretical Frame

A. Purpose

The main purpose of my dissertation case study is to explore how agrifood sectoral systems of innovations actors join in advocacy groups, taking common strategies to influence the US nanotechnology research agenda and it links with sustainability issues.

B. Unit of Analysis

The main unit of analysis will be the agrifood nanotechnology research agenda in the US, which include institutions, and actors such as, Federal agencies, agrifood companies, researchers, NGO, who organized in coalition groups seek to influence the research agenda.

C. Unit of Selection

The unit of analysis will be actors of the agrifood sector, such as researchers, NGOs, policy makers, public managers in the United States, utilizing the bibliometric analysis I will select the actors that are involve in research activities in agrifood nanotechnology. Therefore, the selection criteria that I will utilize to select the people that I will interview are:

1. The name and contact information of researchers will show up from the selection dataset of nanotechnology agrifood articles obtained from my bibliometric

analysis, and from the USDA CRIS and NSF searching dataset of nanotechnology projects period 2000-2010.

2. The name and contact information of policy makers and governmental actors will be obtained from the list of public organizations that support nanotech agrifood research.

3. The name of other actors, such as NGOs and donors, will be obtained from several sources, such as interviews with researchers and policy makers, internet searching, and literature review.

D. Dimension variables

The dependent variable utilized in this research is the "nanotechnology research agenda setting respect to the orientation towards sustainability issues", which is measure in terms of nanotechnology R&D oriented to reduce environmental and social effects. The agrifood SSI is evaluated respect to three dimension variables:

- Knowledge and technologies
- Actors and networks
- Institutions

The independent variables are those related to the agrifood nanotechnology research sector in the US:

- Number and types of research disciplines and evolution in the last decade.
- Networking research performance: Number of publications, patents, and projects, regular meetings, conferences, workshops.

- Advocacy coalitions: numbers of coalitions conformed by NGOs, consumer associations, farmer organizations, and other civil organizations participating, researchers, business organizations, etc. who share common beliefs respect to the nanotechnology research in the agrifood sector.
- Resources of advocacy groups: public opinion, information respect to cost/benefit of using nanotechnology research in the agrifood sector, financial resources available and skillful leadership inside each coalition.
- Beliefs advocacy groups: deep core beliefs, policy core beliefs, goals, and arguments respect the use of nanotechnology in agrifood sector, etc.
- Legal framework: Institutions involve in agrifood nanotechnology research activities, risk management plans, mitigation programs, etc.

Data for assessing variables in the three dimension categories are collected from primary and secondary source, which include bibliometric analysis of agrifood nanotechnology, personnel CVs, background documentation, such as reports and websites, and interview with relevant actors.

II Data Gathering Plan

A. Sources and Sequence of Data Gathering

The stages in the conduction of the case studies data gathering are:

- Preliminary data gathering
- Interviews with relevant actors
- Follow-up request (email, phone, Skype)

B. Preliminary data gathering

Preliminary data is gathered before selection of actors, with the information obtained from the bibliometric analysis, which will provide information of researchers, collaborations, research area, organization, and year of publications. Additionally I will conduct a web searching for actors and potential interviewees, collecting information of CVs, addresses, contact information and organization's websites.

C. Interview with relevant actors

The procedure of my research included site visits and interviews with relevant actors by each case study which is be selected from the preview step. I developed a list with candidates to the interviews from my bibliometric analysis. The interview sequence as follow:

i. Develop a list of potential interviewees with current contact information

a) Selection of actors by area of research, organizations,

b) Develop a strategy to conduct the visit in cases that it is possible, or utilize alternatives, such as phone interviews or Skype interview.

c) Create a standard letter to contact potential interviewees.

ii. Contact interviewees to organize the visit

a) Arrange schedule

iii. Visit the sites and conduct the interviews

a) Conduct interviews (request to type record and take notes)

b) Request additional materials and list of potential new relevant interviewees

iv. Write site visit report and interview report

a) Catalogue collected data

b) Clean-up interview notes

c) Write short report about individual observations

d) Post site visit data on Nvivo software in internal website

D. Determine Missing Data and Follow up

From the data compiled from the site visit and interviews, I assessed whether topics needed further clarification.

v. Interview Questions

1) Introduction: Short introduction to explain about my research and objective of the interview and I gave each interviewee the consent form, which explain that my research, what types of questions I will ask, how I will use the data, anonymity and confidentiality. I will ask for permission to conduct interview and record conversation.

2) Consent: I gave each interviewee a consent form, which explain that my research , what types of questions I will ask, how I will use the data, anonymity and confidentiality. I will ask for permission to conduct interview and record conversation.

A.) **General Question to all interviewees**

1.) Could you please make a short description of your background?

2.) What are your current work/duties?

3.) What are the main goals/missions of your organization respect to agri-food nanotechnology? These goals have changed over time?

B.) Specific questions to Federal Agency Managers

C1.) When nanotechnology research began to be part of your organization research portfolio? And if the research orientation has changed since then?

C2.) How nanotechnology research fit with respect to the overall research strategy of your organization?

C3.) There is any issue of concern with respect to conduct a nanotechnology research agenda in the agriculture and food sector?

C4.) How is nanotechnology research agenda supportedin your organization? How it has changed during the last years? There are other programs that compete for funding inside of your organization? How you set the funding budget to nanotechnology research? Who is involved in this process?

C5.) There are channels of communication and collaboration in relation to nanotechnology issues with other departments inside of your institutions, and outside with Federal agencies and other public organizations?

C6.) Which nanotechnology initiatives have been successful, why? How can you tell (metrics)? Who will use knowledge/product/technology? Who will benefit? How?

C7.) Do you have opportunities to conduct public outreach about the nanotechnology research supported by your organization?

Thank you, and ask for other contacts and for follow up

C.) Specific questions to NGOs and Social Organizations

D1.)What are the main issues about the use of nanotechnology in the agrifood sector? And when your organization started to be involved in the nanotechnology debate?

D2.) What is your organization position respect to the current public research agenda in relation to agrifood nanotechnology?

D3.) What kind of nanotechnology research in the agrifood sector should be promoted by public funding? and Why?

D4.) Has your organization take any action in order to influence the nanotechnology public debate? If yes what?

D5.) There are channels of communication and collaboration in relation to nanotechnology issues with Federal agencies and other NGOs and public organizations?

D6.) If answer to D5 is yes, then name the partners and what resources have been involved in the collaboration

D7.) Have you participate in other policy debates? (GMOs, Environmental, etc)

D8.) If answer to (D7) it positive, then: these other campaigns involved the same partners as the nanotechnology debate?

D9.) Which (nano) projects /campaign/ Advocacy outreach have been successful, why? How can you tell (metrics)? Who will benefit? How?

Thank you, and ask for other contacts and for follow up

D.) Specific questions to researchers and research organizations

E1.) When you started your research in nanotechnology?

E2.) What kind of applications you can obtain from your research? How far out are they? Who will work with them? To whom benefit? Affect?

E3.) Why work on nano in agrifood? What is your vision about nanotechnology in agrifood sector?

E4.) Have you opportunities to interact with Federal Agencies to dialogue respect to the orientation of nanotechnology research agenda?

E5.) Have you noticed chances in research policy of the public nanotechnology research in the agrifood sector? What type of change? Who promoted these changes?

E6.) What factors do you think have affected the development of the agrifood nanotechnology research in the US?

E7.) Do you think that there are enough public funding resources to conduct research in agrifood nanotechnology?

E8.) Which (nano) projects/products/policies have been successful, why? How can you tell (metrics)? Who will use knowledge/product/technology? Who will benefit? How?

E9.) Have you been active in relation to any policy issue related to nanotechnology?

E10.) Who do you interact with? Who are your close colleagues? Project partners? What resources used?

- In same organization
- In other research institutions or organization

- Government (political priorities)

- Business
- NGOs
- Users/citizens/practitioners (farmers, extension services, etc)

E11.) Have you the opportunity to conduct public outreach about your research, such as dialog with social actors? Why?

Thank you, and ask for other contacts and for follow up

III Data Analysis Plan and Reporting

1. Data Analysis

The case study data is composed by my interviews notes, transcriptions, and general observations.

The data on the variables within each case was compared and contrasted to understand how the development of the sectoral system of innovation affects the direction of the R&D to a more sustainable development.

2. Report

A comparative case report was generated with the following outline:

a) General information of the sectoral system of innovation and research and or activities focus, description of advocacy groups

b) Findings on collaborations and networks

c) Findings in sectoral structure and interactions

d) Conclusions on activity development, support, performance and contributions

APPENDIX B.

KEYWORD STRATEGY SEARCH

Crop-specific search terms for the agri-food analysis

**adzuki bean
**agriculture
    ^agronomic$
    farming
    ^agricultural$
    agri[a-z]*
    agro[a-z]*
**alfalfa
    ^medigaco sativa$
**allium cepa
**almond
**amaranth
**animal production
    ^Animal Medicine$
**apple
    ^apple pollen$
    ^malus domestica$
**apricot
    ^prunus ameniaca$
**artichoke
    ^cynara cardunculus$
**asparagus
    ^asparagus officinalis$
**aspergillus niger
**avena sativa
    ^oats$
**banana
    ^banana plants$
    ^musa acuminata$
**barley
    ^hordeum vulgare$
**bean
    ^beans$
    phaseolus
**beef

**beer
**betel nut
    ^areca catechu$
**betel palm
**betel pepper
**blueberry
    ^genus vaccinium$
**bluegrass
**botrytis cinerea
    botritis-cinerea
**brassica
    brassica-jucnea
**brassicca napus
**brazil nut
**breadfruit
**broadbean
**buckwheat
**c-3 species
**c-4 species
**cabbage
    ^capitata$
**cacao
**camellia sinensis
**canola
**cantaloupe
**capsicum
**carob
**carrot
    ^daucus carota$
**cashew
    ^Anacardiaceae occidentale$
**cassava
    ^Manihot esculenta$
**castor bean
**cattle
**cereal
    cereal crops
**cheese
**chickpea
    ^cicer arietinum$
**chicory
**chinese cabbage
**citrus
    citrus plants
**coconut
**coffee

^coffee bean$
**corn
^maize$
maize
**cotton
^Gossypium$
**cowpea
^Vigna unguiculata$
**cranberry
^Vaccinium$
**crop
^crops$
**cucumber
^Cucumis sativus$
**cucurbita
**cultured roots
**currant
**date palm
**drought
^drought stress$
**eggplant
^Solanum melongena$
**Fertilizer
fertiliser[a-z]*
fertilizer[a-z]*
**fescue
**flax
**flowers
floral development
**food production
food sensing
food safety
food packaging
^food aplications$
^food packaging material$
**fruit
**fruit tree
**fungicide
fungici[a-z]*
**fusarium
**ginger
**grape
**grape fruit
**grass
grass land
**guava

**hemp
**herbicide
    herbici[a-z]*
**insecticide
    insect[a-z]*
**kola nut
**legume
**legumes
**legumes seeds
**lemon
**lentil
    ^Lens culinaris$
**lettuce
    ^Lactuca sativa$
**livestock
**mango
    ^Magnifera indica$
**meat
**milk
**millet
**mulberry
    ^Morus$
**muskmelon
**oat
    ^Avena sativa$
**oil palm
**okra
    ^Abelmoschus esculentus$
**olive
    ^Olea europaea$
**onion yellows
    ^yellow onion$
    ^Allium cepa$
**opium poppy
**papaya
    ^Carica papaya$
**parsnip
    ^Pastinaca sativa$
**pea seeds
    ^pisum sativum$
**peach
    prunus persica
**peanut
    arachis-hypogara L
**pear
**peaseeds

^pisum sativum$
**pepper
**pesticide
pest_control
pesticid[a-z]*
pest control
^nanobiopesticide$
^biopesticide$
**pineapple
^Ananas comosus$
**pistachio
^Pistacia vera$
**plant pathogen
plant disease
^phytopathogen$
**plant seed
**plough land
plough-land
**pomegranate
^Punica granatum$
**potato
^solanum$
^solanum-tuberosum$
^solanaceae$
**Poultry
**puccinia coronata
**quinoa
**radish
^Raphanus sativus$
**raspberry
Rubus
**rhubarb
^Rheum rhabarbarum$
**rice
^oriza glaberrima$
rice-grain
O. rufipogon
^oryza sativa$
**rye
^Secale cereale$
**ryegrass
^Lolium perenne$
**seed transmission
^seed protein$
^plant seeds$
^seed morphology$

**seedling
**sesame
    ^Sesamum indicum$
**sisal
    ^Agave sisalana$
**soil
    soils
**soil-root
    ^endomycorrhizal fungi$
    ^mycorrhizal$
**sorbus domestica
**sorghum
**soybean
    ^fabaceae$
    soybean rust
**squash
**strawberry
    ^Fragaria$
**sugar beet
    ^Beta vulgaris$
**sugar cane
    ^Sacharum$
    ^sugarcane$
**sunflower
    ^sunflower breeding programs$
    ^Helianthus annuus$
**sweet cherry
    ^Cerasus$
**sweet potato
    ^Ipomoea batatas$
**taro
    ^Colocasia esculenta$
**tobacco
    ^Nicotiana$
**tobacco-mosaic-virus
**tomato
    lycopersican spp
    ^solanum lycopersicum$
    tomato plants
**trichoderma
**tung
    ^Vernicia fordii$
**turnip
**vegetables
**veterinary
    veterin[a-z]*

**watermelon
    ^cucurbitaceae$
**weed
    invasive weed
    weeds
    ^parasitic weeds$
**wheat
    ^triticum$
    wheat-triticum-aestivum
    wheat straw
    wheat breeding program
**wild forage grass species
**wine
    ^Vitis vinifera$
**zucchini

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